Volume XXXIII September-October 1938 Number 6

Economic Geology

and the

Bulletin of the Society of Economic Geologists

CONTENTS

Dislocated Inclusions in Gold-Quartz Veins at Grass Valley, California ..... *Rollin Farmin* 579

Manganese in the Montreal Mine, Montreal, Wisconsin ..... *R. M. Dickey* 600

A "Red Beds" Type Copper Occurrence, Wyoming County, Pennsylvania .. *Robert D. Butler* 625

A Dip-Needle Survey of the Toivola-Challenge Mine Area, Michigan ..... *Carl A. Lamey* 635

Effect of a Sea Level Canal on the Ground-Water Level of Florida—A Reply .. *Sidney Paige* 647

Discussion and Communications:

Geology in Modern Life ..... *C. H. Behre, Jr.* 666

Kalgoorlie Geology Re-Interpreted ..... *J. K. Gustafson* 667

Reviews:

Geology and Ore Deposits of the Tombstone District, Arizona (Butler, Wilson and Rasor) ..... *J. B. Tenney* 675

Die Lagerstätten der Nutzbaren Mineralien und Gesteine, Bd. III, Teil 2 (Steinsalz and Kalisalz) ..... *W. S. Bayley* 678

Die Metallischen Rohstoffe, Heft 2 (Krusch) ..... *W. S. Bayley* 678

Physiography of Eastern United States (Fenneman) 678

Regionale Geologie der Erde: Vol. I, Pt. 5, Afrika (Hennig); Vol. II, Pt. 2, Northwestern Europe, Caledonides (Bailey and Holtedahl); Pt. 3, Mittel-und Westeuropa (Becker) 679

Books Received ..... *J. D. Bateman* 680

Society of Economic Geologists:

Program of Fall Meeting at Knoxville, Tenn 682

Scientific Notes and News 684

PUBLISHED SEMI-QUARTERLY

Five Dollars a Year, Seventy-five Cents a Copy

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

Prince and Lemon Streets, Lancaster, Pa.

Entered as second-class matter, March 30, 1906, at the Post Office at Lancaster, Pa., under the Act of Congress of March 3, 1879

SCIENCE & TECHNOLOGY

EASTERN MICHIGAN UNIVERSITY LIBRARY YPSILANTI

Economic Geology

and the

Bulletin of the Society of Economic Geologists

Issued Semi-Quarterly and sent to subscribers on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 15.

Manuscripts for publication should be sent to the Editor, **ALAN M. BATEMAN, at Yale University, Yale Station, New Haven, Conn.** It is requested that contributors exercise care in writing *scientific* and *proper names.* References to other publications should be in accordance with the forms used in the pages of this journal. The manuscript should be typewritten with double space lines and must be preceded by *a brief abstract.* Galley proof will be sent authors only where a request to this effect accompanies the manuscript, or when, in the editor's opinion, the subject matter is such as will require correction by the author.

Reviews should conform to the journal usage. Review Committee: The Editor, C. H. Behre, L. C. Graton, J. T. Singewald, Jr., J. Gilluly, A. F. Buddington, W. H. Newhouse.

Books and Pamphlets for review should be sent to the Editor.

Reprints. Contributors desiring reprints of their papers may obtain them by filling out the order slip which will be attached to the galley proof when it is sent to the author. Provided the order slip is received by the editor, *with the return of the proof,* 50 reprints without covers will be furnished without charge. Reprints of discussions and informal communications are not furnished free of charge except when they exceed four pages in length when 50 will be supplied without charge. Reprints of reviews are not supplied. Additional reprints will be furnished at approximately the rates given in the table below when ordered *in advance of publication.* The rates apply only to plain text, with line engravings. Papers containing folded maps or plates will be more expensive.

The following rates *do not* include free carriage. *Postage or express must be paid by the author.*

	4pp.	8pp.	12pp.	16pp.	20pp.	24pp.	28pp.	32pp.
50 copies.....	$2.75	$4.30	$6.50	$7.00	$9.00	$10.25	$11.75	$12.50
100 "	3.50	5.25	7.75	8.50	10.75	12.50	14.50	15.50
200 "	4.50	6.75	10.25	11.50	14.25	17.00	20.00	21.50

The price of *covers,* of same style of type and paper as the cover of the journal with simple title printed thereon, is for the first 50 copies $3.00; additional covers 2 cents each. Plates printed on one side, $2.00 for the first 50, and 1½ cents for additional ones; printed on both sides, $3.00 for the first 50, and 2¼ cents for additional ones.

Single copies of reprints (without covers) of many of the articles published in volumes issued since 1926 (Vol. XXI) are available at the following prices, upon application to the Business Editor, at Urbana, Illinois.

1-4 pp. 15c	5-8 pp. 20c	9-12 pp. 25c	13-20 pp. 30c	21-28 pp. 35c
29-36 pp. 40c	37-44 pp. 45c	45-52 pp. 50c	53-60 pp. 55c	61-68 pp. 60c

If illustrated by plates, add 3c for each plate if printed on one side, and 5c if printed on both sides.

Subscriptions. The price of the journal to subscribers in the United States, Cuba and Mexico is 75 cents for a single copy, or $5.00 a year for eight numbers. To subscribers in Canada, Spain, and countries in Central and South America, except Dutch and French Guiana, the annual rate is $5.30; in other countries, $5.75.

Forwarding. Subscribers wishing their journal to be forwarded to a new address should leave postage for that purpose with the Postmaster at their old address.

Missing numbers will be replaced without charge if claim is made within four weeks after the date of issue of the following number, provided that the neglect to receive them is not due to neglect to arrange for their forwarding.

Remittances should be made payable to the **ECONOMIC GEOLOGY PUBLISHING COMPANY,** and should be mailed to **W. S. BAYLEY,** Business Editor, Urbana, Illinois, to whom also all **Business Communications** should be addressed.

Foreign Agents. Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4, British Agents. Max Weg, Königstr. 3., Leipzig C. 1, Germany, Agents for Europe. The Maruzen-Kabushiki-Kaisha, 6 Nihonbashi Tori Nichome, Tokyo, Japan, Agents for the Orient.

Indexed in the Industrial Art Series.

LANCASTER PRESS, INC., LANCASTER, PA.

ber 15.
AN, at
exer-
l be in
e type-
will be
in the

C. H.
se.

filling
Pro-
without
ications
will be
will be
of pub-
folded

by the

simple
Plates
on both

olumes
to the

nted on

uba and
ibers in
Guiana,

address

weeks
n is not

LISH-
Urbana,

n, E. C.
be. The
Orient.

ASTER, PA.

ECONOMIC GEOLOGY

A SEMI-QUARTERLY JOURNAL

EDITOR: ALAN MARA BATEMAN
Yale University, New Haven, Connecticut

BUSINESS EDITOR: WILLIAM SHIRLEY BAYLEY
University of Illinois, Urbana, Illinois

ASSOCIATE EDITORS

WALDEMAR LINDGREN
Mass. Institute of Technology, Cambridge, Mass.

G. F. LOUGHLIN
U. S. Geological Survey, Washington, D. C.

C. N. FENNER
Geophysical Laboratory, Washington, D. C.

B. S. BUTLER
Univ. of Arizona, Tucson, Ariz.

W. E. WRATHER
Dallas, Texas

HEINRICH RIES
Cornell University, Ithaca, N. Y.

I. M. GOUBKIN
Moscow, U. S. S. R.

PAUL RAMDOHR
Univ. of Berlin, Germany

CHARLES KENNETH LEITH
University of Wisconsin, Madison, Wis.

E. C. ANDREWS
Sydney, Australia

E. L. DEGOLYER
New York, N. Y.

E. S. MOORE
University of Toronto, Toronto, Can.

PER GEIJER
Royal Technical University, Stockholm, Sweden

TAKEO KATO
Imperial University, Tokyo, Japan

ALEX. L. DU TOIT
Johannesburg, South Africa

J. A. DUNN
Geological Survey, Calcutta, India

PUBLISHED BY

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

SOCIETY OF ECONOMIC GEOLOGISTS

THE PUBLICATIONS OF WHICH CONSTITUTE
A PART OF THIS JOURNAL

OFFICERS FOR 1938

D. H. McLAUGHLIN.....*President*
W. D. JOHNSTON, JR.....*Secretary*
A. C. VEATCH.....*Pres. Elect*
F. F. GROUT.....*Vice-President*
W. B. HEROY.....*Treasurer*
E. S. MOORE.....*Vice-Pres. Elect*

Councilors

1938	*1939*	*1940*
G. R. MANSFIELD	G. H. ASHLEY	O. E. MEINZER
H. B. KÜMMEL	C. H. BEHRE, JR.	F. H. LAHEE
E. L. BRUCE	A. W. PINGER	I. B. JORALEMON

Regional Vice-Presidents

CARL BUGGE.....Oslo, Norway.....*For Europe*
A. M. HERON.....Calcutta, India.....*For Asia*
E. T. MELLOR.....Johannesburg, South Africa.....*For Africa*
WM. F. JAMES.....Toronto, Canada.....*For North America*
W. F. WALKER.....Oroya, Peru.....*For South America*
H. C. RICHARDS.....Brisbane, Australia.....*For Australia*

Executive Committee

D. H. McLAUGHLIN, *Chairman* — ALAN M. BATEMAN, *Vice-Chairman*
EDWARD SAMPSON — ALLEN W. PINGER — HUGH E. McKINSTRY

Finance Committee

ALAN M. BATEMAN, *Chairman* — L. C. GRATON — JAMES T. DUCE
ARTHUR NOTMAN — W. B. HEROY — D. H. McLAUGHLIN

Program Committee

PHILIP KRIEGER, *Chairman* — C. H. BEHRE, JR. — W. D. JOHNSTON, JR.

Committee on Publications

B. S. BUTLER, *Chairman* — E. L. DeGOLYER — W. C. MENDENHALL

ECONOMIC GEOLOGY

VOL. XXXIII SEPT.–OCT., 1938 No. 6

DISLOCATED INCLUSIONS IN GOLD-QUARTZ VEINS AT GRASS VALLEY, CALIFORNIA.

ROLLIN FARMIN.

ABSTRACT.

The mesothermal gold-quartz veins at Grass Valley, California, contain many inclusions of country rock in quartz, some of which are broken and the segments separated. When the quartz is removed from the inclusions they can be reassembled into larger, original units of country rock. Adjacent walls of the veins have not shared in the movements that dislocated the inclusions and no evidence of faulting is found in the massive quartz matrix, which exhibits features of original texture. Dislocation of the fragments is attributed to thrust from an injected, vein-forming solution, which forcibly entered rock fractures and spread apart their walls.

INTRODUCTION.

Object.—The study of vein textures has yielded much information about the process of vein formation and study of an individual feature of vein structure may yield specific information about the nature of this process. The present study is centered on the fragments of country rock included in quartz veins, especially on evidence as to transportation of the inclusions without corresponding movements of the adjoining quartz and country rock.

Earlier Studies of the Veins.—Waldemar Lindgren's early report [1] on the geology of the district emphasized the trend toward detailed structural mapping and petrographic research and is still the only comprehensive treatise on the area. He classes the gold-

[1] Lindgren, W.: The gold-quartz veins of Nevada City and Grass Valley Districts, Cal. U. S. Geol. Surv. 17th Ann. Rep., Pt. II, pp. 1–262, 1896; U. S. Geol. Surv. Geol. Atlas, Nevada City. Special Folio 29, 1896.

quartz veins as mesothermal and attributes their emplacement to deposition in open fissures from dilute, aqueous solutions of magmatic origin. Some subsequent authors [2] have agreed with his view; others have held that the veins were deposited either by replacement of crushed rock marginal to fracture planes, or as ore-magmas.

The veins of the Mother Lode district, south of Grass Valley, are of similar geologic type: Knopf [3] has suggested that they were deposited by the action of magmatic gas exhalations, which derived the materials for the veins by alteration and leaching of the wall rocks; reopenings of the vein, possibly supplemented by the pressure of growing crystals, aided in building up composite veins.

At the Alleghany district, 25 miles north of Grass Valley, Ferguson [4] concluded:

> If the grain of the quartz is original, the textural conditions are best met on the supposition that the quartz which filled the fissures passed through a viscous, gelatinous, or slushy state prior to crystallization. If, on the other hand, the present grain of the quartz is the result of recrystallization, no conclusion can be drawn from the texture.

[2] Hoover, Herbert C.: Some notes on "Crossings." Min. & Sci. Press, pp. 166–7, Feb. 29, 1896. The veins were called true fissure fillings.

MacBoyle, E.: Mines and mineral resources of Nevada County, Cal. State Min. Bur., pp. 1–270, 1919. Views closely accord with Lindgren's.

Howe, Ernest: The gold ores of Grass Valley, Cal. ECON. GEOL., vol. 19, pp. 595–622, 1924. Replacement considered principal mechanism of deposition. In discussion (pp. 620–22), Lindgren reaffirmed his conclusion that filled, open fissures were important in the veins at Grass Valley, but conceded that replacement was cooperative: J. E. Spurr stated that he considered the veins typical of the ore-magmas.

Knaebel, J. B.: The veins and crossings of the Grass Valley District, Cal. ECON. GEOL., vol. 26, pp. 375–398, 1931. The relation of the veins and the "crossings" was described, based on a microscopical study.

Johnston, W. D., Jr., and Cloos, Ernst: Structural history of the fracture systems at Grass Valley, Cal. ECON. GEOL., vol. 29, pp. 39–54, 1934. A detailed synthesis of the structural history is presented.

Johnston, W. D., Jr.: Vein-filling at Nevada City, Cal. Bull. Geol. Soc. Am., vol. 49, pp. 23–34, 1938. The veins are interpreted as deposits built up by alternate opening of the fissures and vein filling. The bases for this conclusion will be given in his forthcoming Professional Paper.

[3] Knopf, Adolph: The Mother Lode system. XVI Int. Geol. Congress Guidebook 16, p. 51, 1933; The Mother Lode system of California. U. S. Geol. Surv. Prof. Paper 157, pp. 25, 47, 1929.

[4] Ferguson, H. G. and Gannett, R. W.: Gold quartz veins of the Alleghany District, Cal. U. S. Geol. Surv. Prof. Paper 172, p. 86, 1929.

Basis and Scope.—This paper is based on observations made by the writer in the course of geologic field work on certain veins in the Grass Valley district during the last 4½ years and on incidental study of vein inclusions during several preceding years in the principal mining districts of Utah. The conclusions that will be stated refer specifically to veins that lie in the central portion of the Grass Valley district.

Acknowledgments.—For the opportunity to carry on this study and for permission to publish the findings, the writer is indebted to Mr. Errol MacBoyle, Executive of Idaho Maryland Mines Corp. The generous criticism and advice that have been given by Dr. Waldemar Lindgren, Dr. B. S. Butler and Dr. Alan M. Bateman are gratefully acknowledged. Mr. John M. Boutwell freely rendered valuable assistance during the preparation of this paper, and colleagues at the mines have aided by daily discussion of the problem.

CURRENT EXPLANATIONS OF ROCK FRAGMENTS IN VEINS.

Vein inclusions have been described frequently and the explanations offered have reflected the several theories of vein genesis held by the authors. They have been explained:

(1) By inclusion of wall-rock rubble in quartz deposited in open fissures;[5]

(2) By incomplete replacement of country rock the vein matrix isolates the inclusions;[6]

(3) By reopening of veins, followed by further mineral deposition and possibly aided by the thrust of growing crystals, rock fragments are broken from the walls and included in the veins;[7]

[5] Lindgren, W.: *Op. cit.*, Pl. VIIb and p. 155.

[6] Bateman, A. M.: Angular inclusions and replacement deposits. ECON. GEOL., vol. 19, pp. 504–20, 1924. A good bibliography of earlier discussions of inclusions is given.

[7] Emmons, W. H.: The state and density of solutions depositing the metalliferous veins. Am. Inst. Min Met. Eng. Trans., vol. 76, p. 312, 1928. Knopf, Adolph: *Op. cit.* Hulin, Carlton D.: Structural control of ore deposition. ECON GEOL., vol. 24, pp. 23–30, 1929.

(4) By inclusion of fragments of country rock broken from the walls by a veindike.[8]

PRELIMINARY DISCUSSION OF THE VEINS AND INCLUSIONS.

Occurrence.—The gold-quartz veins at the Grass Valley-Nevada City district have yielded[9] most of the $157,735,345 gold production of Nevada County from 1880 to 1935 and an important fraction of the $1,259,585,186 produced by California gold placer mines from 1848 to 1934 was derived from the eroded croppings of the veins.

The veins have been described frequently: in form they range from thick, branching sheets of large area to small, irregular lenses and they also occur as complex zones of interlinking veinlets and as mineral impregnations in the rock beyond the quartz boundaries. They are composed chiefly of coarse, milky quartz, ankerite and calcite, containing minor amounts of the metallic sulphides, sericite, chlorite and gold.

The vein matrix includes fragments of country rock that range from microscopic slivers to masses several feet in diameter. Some of the inclusions are rounded and others are angular; some are long, thin septa that occur separately or in layered groups. Most of the inclusions are composed of the country rock that surrounds the quartz[10] but some (as recently observed by the writer) are composed of rocks that do not appear in the immediately adjacent walls.

The inclusions are distributed sporadically through the quartz, in thick clusters at certain points and sparsely at others. They are found in carbonate veins and in narrow, irregular quartz veinlets as well as in the large quartz veins. They appear to be erratically distributed between walls of the veins, although they

[8] Spurr, J. E.: The Ore Magmas. McGraw-Hill Co. N. Y., p. 129 *et seq.*, 1923. Angular inclusions in ore deposits. ECON. GEOL., vol. 20, pp. 766–67, 1925. Many other writers have contributed to the literature on vein inclusions.

[9] These statistics were kindly furnished by Walter W. Bradley, State Mineralogist of California.

[10] Howe, Ernest: *op. cit.*, p. 613, found that the inclusions are all composed of the same rocks that form the immediate vein walls.

have been reported [11] to be more abundant near the footwalls of veins.

"Support" of Included Fragments.—In discussion of angular rock fragments in veins the question has been raised whether or not the fragments are in contact with each other and with the fissure walls.[12] If they are mutually "supported" the quartz may have filled in around them in an open cavity. If they lie "unsupported" in the quartz they are either (1) islands left by incomplete replacement of the country rock, or (2) xenoliths that were moved out of place during vein emplacement. In answer to this question, Emmons [13] wrote: "I believe that a great many of them are actually isolated." He further concluded that many fragments have been isolated by reopening of veins, or by crystallization of material below fragments, or as residuals of replacement. In description of the veins of the Mother Lode, Knopf [14] concluded: "Generally the inclusions are most abundant near the walls of the veins, but in many places some are found far away from the other inclusions."

The question of "support" can be answered readily in mine headings by scaling off the several inches of shattered vein that remains at the face after each round of blasting. Small inclusions can be examined for possible "support" on all sides; in doing this the writer has found that many are wholly "unsupported."

The authors who have objected to the use of angularity and lack of "support" of fragments as criteria of vein mechanics have rightly called those features inconclusive—the problem must be solved by more specific information about each vein.

Alteration of Inclusions.—Most of the quartz veins at Grass Valley are surrounded by envelopes of strongly altered, carbona-

11 Lindgren, W.: *op. cit.*, p. 155, Pl. VII*b*. Spurr, J. E. and Garry, G. H.: Economic geology of the Georgetown Quadrangle, Colorado. U. S. Geol. Surv. Prof. Paper 63, Fig. 69, 1908.

12 Bateman, A. M.: *op. cit.* Weinig, A. J.: Angular fragments in veins. Eng. and Min. Jour., vol. 122, pp. 1020–21, 1926. Talmage, S. B.: The significance of "Unsupported Inclusions." ECON. GEOL., vol. 24, p. 609, 1929.

13 Emmons, W. H.: *op. cit.*, p. 311.

14 Knopf, Adolph: *op. cit.*, p. 25.

tized rock. In the several country rocks the carbonate is supplemented by chlorite, talc, sericite, mariposite, etc. Where the country rock is black slate the alteration is at a minimum; where it is serpentine, a thick lens of talcose ankerite invariably surrounds the vein. Similar alteration is found in fragments of country rock included in the veins: fragments of slate, chert, diabase and porphyrite are less altered than fragments of serpentine and of granitic rocks.

The strongly altered fragments are commonly more or less rounded and occasionally one is found to be cut by a network of veinlets of quartz and carbonate without disturbing the unity of the original fragment or offsetting original banding in it. In a more advanced case, the fragments are reduced to "ghosts" that mottle a nearly uniform vein of quartz and carbonate. Similar occurrences have been described by Howe[15] and interpreted to be evidence of replacement, which he considered to be the principal mechanism operating during the deposition of the veins.

Replacement seems to have been inactive in many of the veins, similar to one on the Mother Lode of which Knopf [16] wrote:

> Inclusions of slate and greenstone in the quartz are common. They are all sharply angular, even those so minute as to be detectable only in thin sections under the microscope. Although all, without exception, have been strongly altered by ore-forming processes, none have been replaced by quartz.

SOME GRASS VALLEY VEIN INCLUSIONS ARE DISLOCATED.

Parts of the veins exhibit composite features, owing to recurrent mineralization and shearing, and inclusions in them are too distorted for correlation. Other parts contain inclusions in a homogeneous quartz-carbonate matrix that does not appear to have been deformed or recrystallized. Even in the latter type of vein, some of the inclusions appear to have been broken and their segments separated in the vein matrix. The critical feature of these dislocations is that neither the quartz surrounding the seg-

[15] Howe, Ernest: *op. cit.*, pp. 616–18.

[16] Knopf, Adolph: *op. cit.*, p. 25.

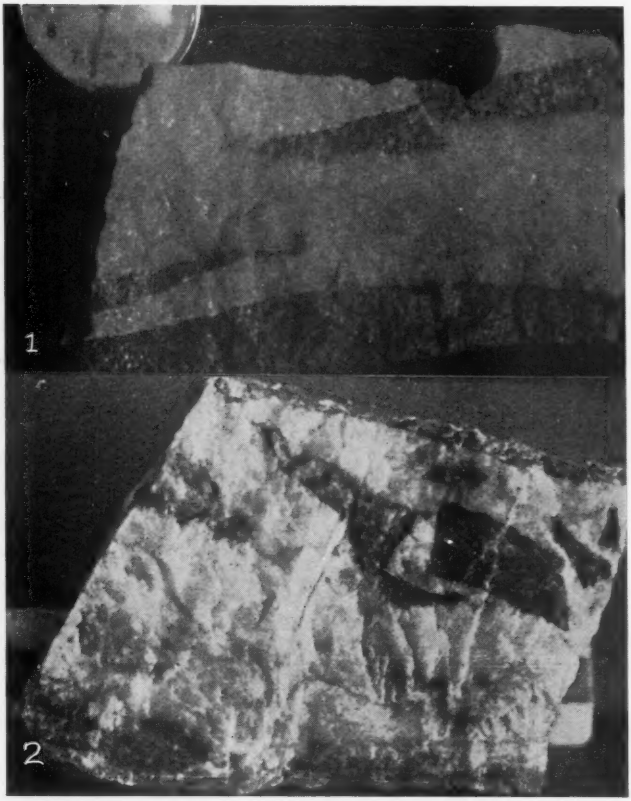

FIG. 1. Simple dislocation of the segments of a septum of wall rock included in a " frozen " quartz vein. The vein walls are not offset and the quartz is not fractured opposite the broken inclusion. The vein walls and the rims of the inclusions are fringed by a narrow, white border of carbonate. (Brunswick mine, 900 level.)

FIG. 2. A dislocated inclusion in quartz. The segments moved obliquely apart, with slight rotation, and a small fragment of wall rock was carried between them. By breaking away the quartz, the segments of the inclusion may be freed and reassembled. (Brunswick mine, 1300 level.)

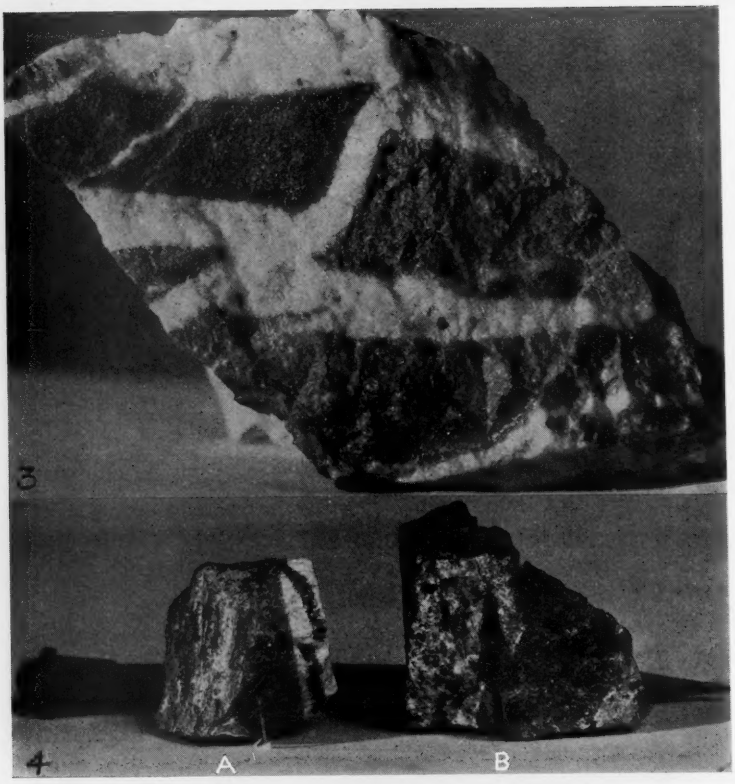

FIG. 3. Ore specimen showing four dislocated masses of wall rock separated by a distance exactly equal to the width of the intervening quartz. (Brunswick mine, 1000 level.)

FIG. 4 (*a*). A narrow veinlet of quartz includes a septum of dark porphyrite; neither wall of the veinlet is offset opposite the break in the septum. The walls and all faces of the inclusion are separated from the quartz by a narrow rim of vein carbonate. (Brunswick mine, 1100 level.)

(*b*) Dark andesite-porphyry including a septum of light colored granodiorite country rock. A small sliver of granodiorite is partly split off from the larger mass but is still attached at the top. Specimen from point indicated by arrow in Fig. 10. A close analogy between *a* and *b* is apparent. (Defender mine. 600 level; Amador County, California.)

ments nor the adjacent country rock appears to have shared in the movements.

Fig. 1 illustrates the simplest type of dislocation found, in which the offset is in prolongation of the plane of the break across the septum. The adjoining rock wall is not similarly dislocated nor is there any trace of a cross-fracture in the surrounding quartz matrix.

In a somewhat more complex case of dislocation (Fig. 2), the segments of the broken inclusion have been separated obliquely in the quartz. The movement was nearly parallel to the exposed surface of the specimen, but one segment receded slightly from the observer.

A further complexity of dislocation is illustrated in Fig. 3, which shows four segments of an inclusion that are separated in the vein. If the matrix were removed the segments could be refitted into place. Many other exposures have been found wherein dislocated inclusions could be reassembled. Howe[17] considered reassembling fragments but concluded "adjacent surfaces would seldom make a perfect match." This is true only because the direction of separation of fragments generally will not coincide with the plane of the surface exposed to view.

Some septa are attached at one end to the wall rock (Fig. 4*a*) and others are entirely separated and lie as "unsupported" masses in quartz. Many of them have been rotated, as in FIGS 4*a* and 5, where a septum of striped, varicolored wall rock has been wedged away from the parent mass by a tongue of quartz and is held at a discordant angle. These inclusions could be rotated back into their original positions if the quartz were removed from them. This is true in three-dimensional fitting—not merely on the random cross-section found on a single surface. In fragments containing "marker" stripes, a fit could be brought about by a rotation as great as 30°, bringing together characteristic, serrate surfaces (Fig. 6). The "marker" dispels any doubt about the correctness of the correlation.

Identification of rotated fragments is especially convincing in

[17] Howe, Ernest: *op. cit.*, pp. 613–14.

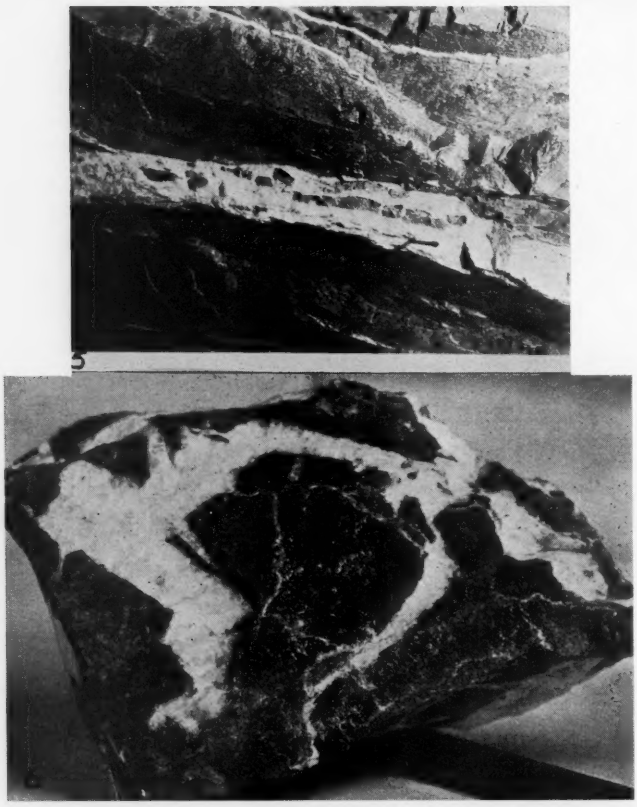

FIG. 5. Horizontal vein and staggered segments of an included septum of wall rock, definitely identified by a dark chert stripe. Some of the segments are offset upward, out of line. The pencil in the lower part of the vein protrudes from a vug in the quartz. (Brunswick mine, 1100 level.)

FIG. 6. The serrate walls of dark diabase encasing the quartz would fit back together if the quartz were removed. The rotation by which they would be swung back into place is hinged at the lower left corner of the specimen, at the tip of the quartz wedge. Several small septa of diabase could be folded back into position along the walls in the upper, left part of the veinlet. (Spring Hill mine, 1100 level.)

diamond drill cores; the machined surface permits good volumetric observation independent of cleavage planes (Fig. 7). The core shown in Fig. 7*b* contains a dark, chloritic stripe that is offset along a sharply curved quartz veinlet. The displacement exactly equals the width of the quartz (a fact that is not in harmony with the hypothesis that replacement was the chief process of deposition.)

CORRELATION OF INCLUSIONS WITH DISTANT ROCK WALLS.

The foregoing descriptions are of small dislocations; the following ones give examples of transportation of fragments of wall rock along the vein to positions they would not have reached if they were developed as fault breccia, dragged along the vein fracture during, or prior to, mineralization. An example of this type of transportation is found in the Brunswick mine; a chert bed is offset only a few feet by a vein fracture, although the quartz includes fragments of chert 6 feet above the upper junction of the vein and the bed. The minor faulting along the vein fracture is reverse and is distributed over several planes in progressive steps. Faulting of this distributive type is thought by the writer to disprove a possible explanation that the fragments were dragged along the fracture by a larger fault movement that later was canceled by back-slipping.

At a number of exposures in the Idaho Maryland and Spring Hill mines the veins contain large, tumbled inclusions of diabase and altered serpentine, although both walls are of one rock type only and evidence for extensive fault drag prior to veining is lacking. The vein fractures are reverse faults, marked by clean shears, and only rarely is the country rock found to be appreciably brecciated or dragged.

A more conclusive example of transportation, found in the Idaho Maryland mine, is in a tight, stringer-like vein in gabbro. The vein matrix is not ribboned or cut by intra-mineralization fault planes and it contains many angular inclusions of diabase and some inclusions of the gabbro country rock (Fig. 8). The only diabase mass found that could have been the source of these

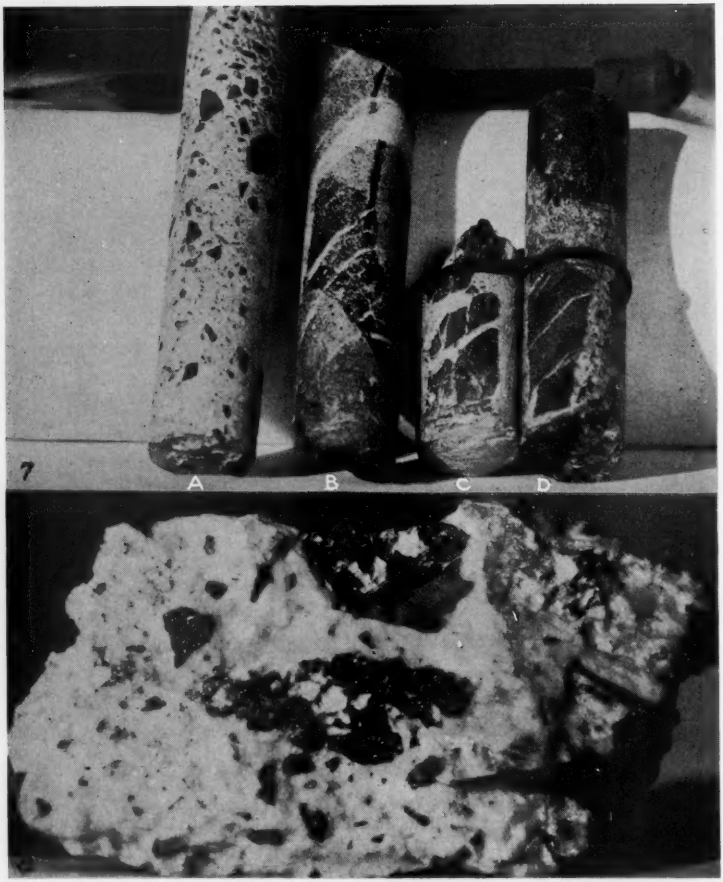

FIG. 7. Cores drilled in the Idaho Maryland mine. (*a*) Cement and included fragments of dark serpentine from a hole redrilled after grouting. The angularity and "unsupported" position of the fragments are similar to those features in the vein inclusions, as in Fig. 8.

(*b*) The dark, chloritic stripe in the porphyrite country rock is offset a distance equal to the width of the "frozen" quartz stringer that cuts it. The curvature of the stringer is so marked that a pre-quartz shear would not have followed it.

diabase fragments is a dike that lies 10 feet behind the footwall and would intersect the vein 20 or 30 feet down the dip. If the dike had been thrust upward on the hanging wall side of the vein fracture, so that it might have left the trains of diabase fragments that now are vein inclusions, the dike would be visible in the hanging wall mine workings—which is not the case. On the other hand, normal faulting along the vein fracture probably would not have elevated diabase breccia above the intersection of the dike with the vein. Another feature unexplained by the hypothesis of fault drag is the great preponderance of diabase fragments over those of the immediate country rock, gabbro.

Local, small-scale transportation of an included fragment is shown in Fig. 10. The country rock of the vein is a ten-foot, vertical diabase dike that is slightly offset by the horizontal vein fracture. The diabase is sheeted by two parallel, quartz-bearing fractures that are offset two inches by the horizontal vein fracture. A septum of diabase that is included in the quartz lies between the offset ends of the sheeted diabase. It is longer than the space between the two steep fractures, but is not fractured. Therefore, the septum has been transported into position athwart the steep, pre-quartz fractures, although it could not have been carried into place by the slight movement along the vein fracture.

DISLOCATED FRAGMENTS OF WALL ROCK IN DIKES.

The similarity between veins and dikes has been considered by many geologists, who have reached diverse conclusions about the

(*c*) Serpentine inclusions in light gray cement, obtained by redrilling a caved hole after grouting it. The separation of the segments of the large inclusion are closely analagous to a similar structure in (*d*).

(*d*) A fragment of dark porphyrite is included and its broken segments are separated by intrusive diorite (light gray).

FIG. 8. Specimen of vein quartz and carbonate (white) including fragments of gabbro country rock (mottled black and white) and numerous angular fragments of gray diabase. The only mass from which the diabase fragments could have been broken is a dike that intersects the vein 20 feet down the dip from this exposure. The inclusion in the upper center of the picture is from the contact of the gabbro and diabase, the upper part being of gabbro. (Idaho Maryland mine, 1000 level.)

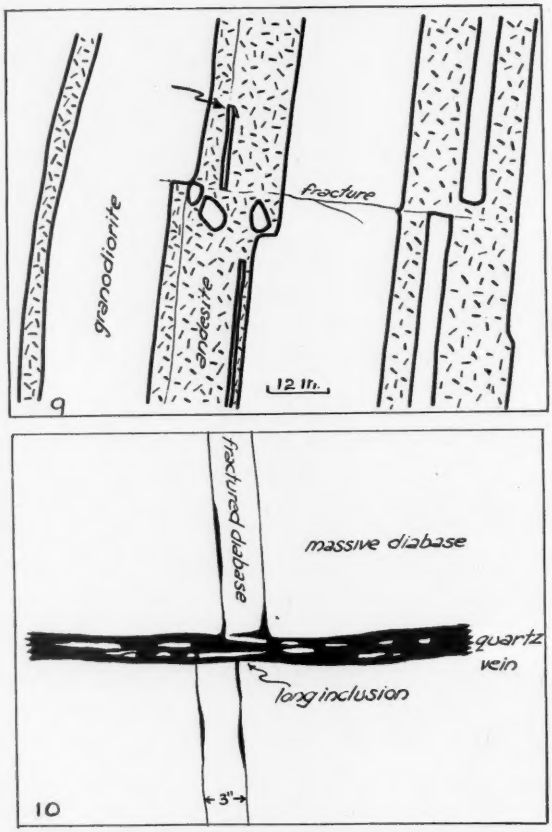

FIG. 9. A vertical sketch from the 600 level of the Defender mine, Amador County, showing andesite-porphyry dikes and included septa of the granodiorite country rock. Fig. 4*a* is a photograph of a specimen collected from the point indicated by the arrow.

FIG. 10. Drawing of a small vein on the Idaho Maryland 1500 level. The indicated "long inclusion" in the quartz vein has been transported or rotated into position because it is not cut by the pre-mineral fracture planes that are slightly offset by the vein fracture.

relationships involved. Development of included wall-rock septa in both suggests that similar mechanisms have operated.

At the Defender mine, Amador County, California, the vein and the granodiorite country rock are cut by post-vein dikes of andesite-porphyry,[18] which furnished some of the lava that caps the nearby hills. Six hundred feet below the base of the lava, along a drift on the vein, the dikes include fragments and septa of the granodiorite that are similar to the vein inclusions at Grass Valley. In Fig. 9 the long, narrow septum included in the middle dike is ¼ of an inch wide and more than 2 feet long, showing no evidence of replacement (assimilation) by the magma. The wider septum is broken and pressed out of line (there is little reason for doubting that the two halves should be correlated because they are of identical width). The displacements were not caused by crosscutting faults because the adjoining rock walls and the other dikes do not show similar offsets. A weak fracture of pre-dike age is seen; it probably bounded the two segments of the septum and was the plane along which the dike walls were offset. At the tip of the narrow septum in the upper central part of Fig. 9, the small sliver of granodiorite is separated from the septum as if it had been wedged aside by the andesite magma. It is shown in detail in Fig. 4*b* and is strikingly similar to the adjoining specimen, Fig. 4*a*, wherein a sliver of wall rock is separated from the main mass by a quartz veinlet. Apparently the septa were pressed apart, both horizontally and vertically, by the intruding magma. Alternative explanations of the occurrence of dislocated septa in dikes would be much the same as those that have been advanced for the isolation of inclusions in veins: (1) that they are islands of wall rock incompletely replaced by the magma; (2) that they were separated by reopening of the dike fracture and the open spaces were filled with more magma of a second generation; (3) that the septa were spread apart by the force of growing crystals in the magma. In view of the well-known violence of near-surface volcanism the alter-

[18] Farmin, Rollin: Hypogene exfoliation in rock masses. Jour. Geol., vol. 14, p. 626, 1937. Additional details of the structure are given.

native interpretations are not convincing. The spreading of the fissure walls by pressure of the invading magma at a depth of somewhat more than 600 feet is relatively peaceful volcanism.

The fact is generally recognized that rock magma can pick up and transport xenoliths and can make a path through country rock by pressing apart fracture walls, if open channels are not available. At Grass Valley, as at many other districts, dikes were emplaced along the same fracture zones that subsequently were followed by the veins. Both solutions encountered nearly identical masses of sheared rock at the time of their entry.

Post-mineral dikes likewise have followed vein fractures. At the Bigelow mine, Sierra City, Cal., the gold-quartz vein is cut by a later, 130-foot, volcanic breccia pipe. The basalt matrix contains an angular rubble of assorted rock types that were picked up by the magma on its upward course toward the volcanic surface, 2400 feet above the mine workings. Sills of basalt, ranging in width from a few inches to five feet, follow along the vein fracture for 1000 feet beyond the pipe. The intruding magma pressed aside blocks of quartz at the rim of the pipe and also along the sills. The sills branch, link from wall to wall of the fracture zone, pinch out and reappear, similar to the quartz lenses alongside. The chief difference in form is that the quartz lenses throw off more stringers than do the basalt sills; this may be attributed to the much smaller load of overlying rock that confronted the basalt during emplacement, because many deep-seated dikes are ramified.

ADEQUACY OF CURRENT EXPLANATIONS OF INCLUSIONS.

Any of the current theories seems to explain adequately the simple occurrence of angular rock fragments in veins. The dislocations, however, present specific problems with which to test the theories.

Did the Fragments of Wall Rock Fall into Open Fissures?—If the veins were deposited by the filling of open fissures, perhaps many of the fragments of wall rock accumulated in them as mutually-supported rubble and subsequently were converted into

inclusions by deposition of quartz around them. Some of the dislocated inclusions could be explained as fragments that fell from the hanging wall of the fissure onto a layer of quartz or silica gel on the footwall. However, deposition of non-crustified quartz on one wall of a vein without simultaneous deposition on the other wall does not seem reasonable, especially in a steeply dipping vein. Deposition would have to continue after a recognizable, segmented fragment fell into the vein, in order to account for overlying inclusions that are found between the marked fragment and its former seat on the hanging wall. Furthermore, this explanation does not account for the segments that have moved upward, not only from the footwall toward the hanging wall, but also up the dip toward the surface.

A final objection to this hypothesis is that the presence of open fissures along the vein fractures at the time of deposition seems inconceivable—at least to this observer. Among the country rocks are fissile slate, chloritic schist, and talcose ankerite that has been derived from serpentine by alteration. These rocks quickly squeeze together the most strongly timbered of mine openings, comparatively near the earth's surface. The idea that continuous, smoothly lenticular, open spaces were present in these rocks at depth, along zones of distributive thrust faulting, seems untenable. It is doubtful that important open spaces could have developed by the thrusting, even in granodiorite. Howe[19] expressed this objection earlier and pointed out the invariable reverse nature of the faults at Grass Valley. Lindgren, in discussion of book structure in fissile rocks, has written:[20]

> It has been thought that this and other features are difficult to explain by the assumption of open cavities. . . . It is improbable that crystallization could have opened the cavities. More likely they were supported by the strong pressure of magmatic waters.

Was Replacement the Chief Process in Vein Emplacement?—The theory that replacement has been the principal process in vein emplacement is unable to account for the fact that some inclusions and vein walls are marked by characteristic, serrate sur-

[19] Howe, Ernest: *op. cit.*, pp. 608, 603.

[20] Lindgren, W.: Mineral Deposits, 2nd Ed., p. 165, 1919.

faces that can be refitted, like pieces of a jig-saw puzzle, if the quartz separating them is removed (Fig. 6). If replacement was active, the wedges and angles of the fragments and of their former seats in the walls would have been modified so that they would no longer fit. Even if hidden faulting is invoked to account for the dislocations, replacement would have modified these surfaces.

Did Obscure, Intra-Mineralization Faulting Dislocate the Inclusions?—The exposures of dislocated inclusions that have been described on foregoing pages have purposely been limited to veins that show the criteria of original texture—vugs, comb textures, isolated grains and clusters of sulphide minerals interlocking with the quartz, and to veins and stringers that are offset only by visible faults. If the vein textures are admitted to be original, the dislocations could not have been accomplished by intra-mineralization faulting because there is no trace of it in most of the exposures. Some of the inclusions that have been slightly offset or rotated might be explained by the crowding of growing crystals during deposition of the quartz but the transportation of fragments could not be thus explained.

The argument may be advanced, ignoring the criteria of original texture in the vein matrix, that the veins and stringers (which now appear to be uniform, massive quartz, "frozen" to the walls and to the inclusions) have actually been fractured, and that their walls moved in such a manner as to transport the fragments to their ultimate positions: and then slipped back into juxtaposition. The evidence of the movements would then be eradicated by a mineralization that filled open spaces or replaced outward from the fracture planes.

Fundamental objections to the explanation are that it leans too heavily on coincidence to be of general application and that it calls for hidden action of processes that ordinarily leave clear-cut trails. Faulting ordinarily develops gouge, breccia, sheeting and ribboning; filling of open fissures marks and supports their walls; metasomatic replacement of any mass tends to duplicate its structure; healed fractures appear as veinlets of secondary minerals. Failure of these features to be visible must be attributed to a

general recrystallization that penetrates to the tips of the stringers in competent rocks which are not recrystallized. It must produce vugs, vacuoles, comb and rosette textures and does not obscure the slips that offset stringers, although it does obscure intra-mineralization fault planes. The burden of proof rests heavily upon the proponent of such a theory.

Individual exposures of the dislocated inclusions are not satisfactorily explained by the theory built around concealed, intra-mineralization faulting. In Fig. 11, the distribution of the

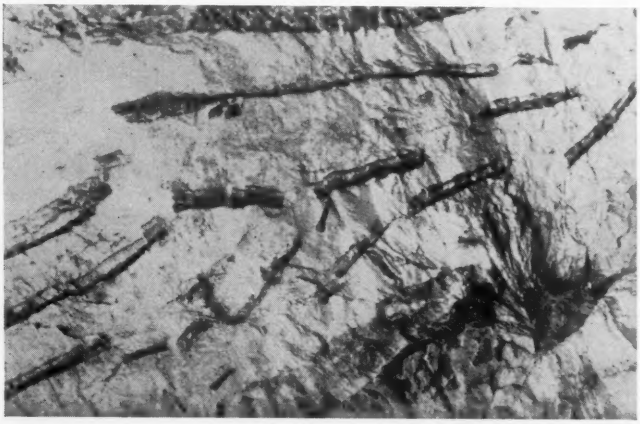

FIG. 11. A staggered train of sub-parallel inclusions of wall rock in a large quartz vein. The central segment (near the pencil protruding from a vug) is characteristic; other segments of the original septum of wall rock can be traced across the field of view. Offsets of the segments are difficult to explain by healed faults because the overlapping septa nearby are unbroken. (Brunswick Mine, 900 Level.)

overlapping and staggered septa, marked by tumbled rotation of the segments, could not be duplicated by a hypothetical series of fault movements along the vein fracture through rigid quartz. Again, in Fig. 6, is pictured an angular rotation that was not achieved by reopening of the vein fracture because no movement

extended beyond the tip of the quartz. Pressure from growing crystals would not cause rotation so markedly out of line with the quartz comb. Similar objections could be based on the distribution of segments of inclusions in many other exposures that have been studied.

Dislocated Inclusions Interpreted as Xenoliths Carried by an Injected, Vein-Forming Solution.—The inclusions that have been dislocated without corresponding dislocation of the neighboring inclusions and rock walls are here interpreted as xenoliths that have been peeled from the fissure walls and transported by an injected, vein-forming solution. The sluicing action of the fluid is attributed to successive surges originating in a telluric pressure capable of causing it to penetrate upward through dense, semi-plastic shear zones, as well as through fractured, brittle rocks. Pressure of the fluid apparently spread apart the walls [21] of tightly compressed fissures, and held them open during passage of the fluid onward to higher levels until movement ceased (in much the same manner that rock magmas enter ground).

Transportation of xenoliths is familiar in rock magmas and is spectacular in "pebble-dikes" where xenoliths have been carried upward more than 6,000 feet [22] by mineral-bearing fluids. The development, rotation and dislocation of inclusions in the gold-quartz veins is interpreted to be a similar process, in a fluid intermediate between the rock magmas and the probably more gaseous transporting fluid of the "pebble-dikes." Explanation by this process does not call for a fortuitous chain of events that would be caused by diverse forces, nor does it rely on faults that have been obscured by a recrystallization for which there is no evidence. The dislocations of inclusions that have been described in this paper are all easily explained by surgence of the vein-forming solution, especially if it is thought to be a comparatively concentrated one, from which the more volatile fractions either

21 Graton, L. C.: Reconnaissance of some gold and tin deposits of the Southern Appalachians. U. S. Geol. Surv. Bull. 293, p. 59, 1906. Lindgren, Waldemar: Mineral Deposits, 3rd Ed., p. 173, 1928.

22 Farmin, Rollin: "Pebble-Dikes" and associated mineralization at Tintic, Utah. ECON. GEOL., vol. 29, pp. 356–70, 1934.

escape during crystallization, to alter the wall rocks, or remain behind as fluid in vugs and vacuoles. Composite veins may have been built up by repeated surges of the solution that forcibly reopened and filled the vein fractures and produced many of the small, intra-mineralization faults that usually have been ascribed to outside stresses.

The evidence bearing on the density and viscosity of the vein-forming solution is not very direct. Ferguson gave reasons for concluding [23] at Alleghany that the quartz was probably in a slushy or gelatinous state prior to crystallization, in order to support sulphide crystals and inclusions; and Knaebel [24] described similar evidence at Grass Valley in the development of doubly terminated quartz crystals in vein carbonate. The dislocation and transport of inclusions by the vein-forming solution supports the interpretation that the solution probably became slushy or gelatinous before it stopped moving. A less likely alternative is that the specific gravity of the inclusions and of the solution were nearly the same so that there would be little sinking of the inclusions in a highly mobile fluid.

CONCLUSIONS.

Vein matrix exhibiting original texture includes fragments of wall rock that have been dislocated without corresponding dislocation of the enclosing quartz and wall rock. Most of the current explanations of inclusions do not readily account for the dislocations; the writer attributes them to pressure from an injected, vein-forming, magmatic solution that was relatively concentrated.

IDAHO MARYLAND MINES CORP.,
GRASS VALLEY, CAL.,
June 3, 1938.

[23] Ferguson, H. G. and Gannett, R. W.: *op. cit.*, p. 81, 82.
[24] Knaebel, J. R.: *op. cit.*, p. 385.

MANGANESE IN THE MONTREAL MINE, MONTREAL, WISCONSIN.

R. M. DICKEY.

ABSTRACT.

The mode of occurrence of manganese and its associated minerals in the manganiferous iron ore bodies of the Montreal Mine is described. It is believed that most of the manganese was contributed to the iron ore bodies by solutions of magmatic origin ascending along transverse or oblique faults from an unknown, but probably granitic, source. The manganese was apparently first deposited as rhodochrosite, subsequently altered to manganese oxides and hydroxides by calcium chloride waters which are thought to have been of juvenile derivation.

INTRODUCTION.

THE Montreal Mine, located at Montreal, Wisconsin, is the largest underground producer of iron ore in the Lake Superior district; it is also the principal source of manganiferous iron ore on the Gogebic iron range. The Montreal is now the westernmost operating property in the Gogebic district; it is adjoined on the east by the Cary Mine, located within the corporate limits of Hurley, Wisconsin, and on the west by the inactive Father Hennepin Mine (Fig. 1). The Cary and Montreal are the only properties now actively producing iron ore in the Wisconsin portion of the Gogebic range.

The Montreal Mine ships two grades of manganiferous iron ore; one averages about 4.5 per cent manganese (dried) and the other about 2.5 per cent. Operations in the property have proceeded to such depth (slightly over 3,000 feet vertically), with a consequent accumulation of data, that it is now believed possible to formulate a logical hypothesis of the origin of the manganiferous iron ores found in the mine. The conclusions reached in this paper are the results of over two years of study of manganese occurrences within the iron ores, and of discussions of the prob-

FIG. 1.

lem with individuals familiar with the circumstances. It is believed that during this period all possible hypotheses that might have any factual basis have been fully considered; all of them, except the one here advocated, have been rejected for various reasons.

PREVIOUS WORK.

The possible genesis of the manganese in the iron ores of the Gogebic district has apparently received but scant attention in the geologic literature.

Irving and Van Hise [1] noted that "manganese is always present in the iron carbonates, frequently in some quantity, and is yet more abundantly found in the ores." This was taken as partial evidence that the iron oxide of the ore deposits was derived from the iron carbonate of the iron formation in which the iron ores occur.

Van Hise and Leith [2] stated:

> . . . the subject has not been specifically studied for the Lake Superior region. It may be noted here merely that the manganese tends to be concentrated in the upper parts of the Lake Superior iron-ore deposits, and that as secondarily concentrated it consists principally of manganese dioxide (pyrolusite) and subordinately of manganese carbonate. . . . In some deposits also the relation is reversed, the iron being above, the

[1] Irving, R. D. and Van Hise, C. R.: Penokee Iron-bearing Series of Michigan and Wisconsin. U. S. Geol. Surv. Mon. 19, p. 282, 1892.

[2] Van Hise, C. R. and Leith, C. K.: The geology of the Lake Superior Region." U. S. Geol. Surv. Mon. 52, p. 560, 1911.

manganese below . . . iron and manganese oxides and clay are the most stable of the common constituents of the belt of weathering, and hence all of them tend to become residually concentrated as compared with other substances originally associated with them. The vertical distribution of these three substances is taken to be a function of their relative stability under various conditions of weathering, but the available information does not seem to warrant more specific statements.

It is inferred by these investigators that the manganese owes its presence in the iron ores to residual concentration, perhaps aided by limited transportation, of the manganese in an originally manganiferous iron formation. The concentrating agent is stated to be downward-moving meteoric water.

Trengove [3] gave as his belief that cold, meteoric waters are incapable of oxidizing manganese carbonate on a scale requisite to explain the abundance of manganese oxides and hydrated oxides in the Lake Superior iron ores, and favored hydrothermal waters and gases as the oxidizing agents. He indicated that perhaps this hypothesis is specifically applicable to the manganiferous iron ores of the Montreal Mine.

All these writers have apparently regarded the manganese as having been originally incorporated in the iron formation during primary sedimentation.

GEOLOGY OF THE MONTREAL MINE.

Stratigraphy.—The geologic succession in the Montreal Mine is, on the whole, typical of that of much of the Gogebic range. The rocks present are of pre-Cambrian age. At the base of the sequence is silicified Keewatin greenstone, composed in part of lava flows, of which the vesicles can still be observed locally.

Overlying the greenstone unconformably are clastic and chemical sediments of Huronian type, which have been fully described by Hotchkiss [4] and are not here considered in detail. Rocks of Lower Huronian age are missing in the mine. The succession of

[3] Trengove, S. A.: The hydrothermal oxidation of manganese minerals. ECON. GEOL., vol. 31, pp. 29–47, 1936.

[4] Hotchkiss, W. O.: Geology of the Gogebic Range and its relation to recent mining developments. Eng. Min. Jour., vol. 108, pp. 443–452, 501–507, 537–541, 577–582, 1919.

Middle Huronian sediments, approximately 1,000 feet thick, is shown in Fig. 2; it consists of the Palms quartz slates and quartzite, and the Ironwood iron formation, made up of the Plymouth ferruginous chert at the base, the Yale slates and interbedded ferruginous cherts, the Norrie ferruginous chert, and the Pence

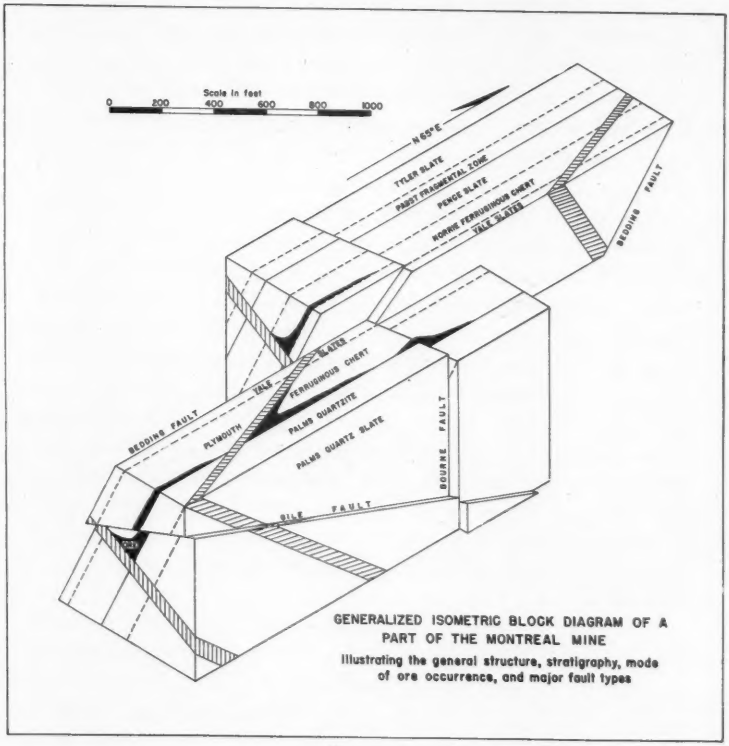

FIG. 2.

slates. The Anvil ferruginous chert number found elsewhere in the district has been identified in small amount above the Pence slates in the Montreal Mine; it has apparently been almost entirely removed by post-Middle, pre-Upper Huronian erosion.

Unconformably above the Middle Huronian rocks is the Upper Huronian Tyler slate, the thickness of which is not accurately known, but in this locality is probably of the order of 8,000 feet. The Pabst fragmental zone, which averages perhaps 60 feet thick in the Montreal Mine, occurs at the base of the Tyler slate.

Lower Keweenawan sediments and Middle Keweenawan flows do not occur within the Montreal boundaries but overlie the Tyler slate north of the property.

Intrusives.—At some time within the pre-Cambrian and following the deposition of the Upper Huronian, the Montreal succession was intruded by a number of basic dikes, both diorites and diabases. These dikes are ordinarily considered to be of Keweenawan age, but it may well be that they were emplaced during the period of orogeny which is known to have occurred [5] in post-Huronian, pre-Keweenawan time. In the Montreal property they range in thickness from a fraction of an inch to about 35 feet. The most prominent exomorphic effects of the dike intrusions upon the Huronian rocks were limited to the production in some instances of a baked zone only a few inches thick adjacent to the contacts; even these narrow zones of baking are not observable in the decomposed or partially-decomposed iron formation. Because these dikes were affected by the earliest faulting known to have taken place during the orogenic history of the iron formation, it is believed that they were emplaced in roughly vertical positions at a time when the Huronian beds were approximately horizontal.

Tilting and Folding.—The Huronian sediments in the Montreal property have in general a monoclinal structure, the beds striking about N. 65° E. and dipping northwest at angles usually varying from 60 degrees to 65 degrees. They show none of the secondary structures ordinarily associated with compressive folding, such as flow or fracture cleavage; consequently, the writer is in agreement with Atwater's belief [6] that they have attained their present attitude through being involved in the tilting of fault blocks.

[5] Atwater, G. I.: Correlation of the Tyler and the Copps formations of the Gogebic iron district. Geol. Soc. Amer. Bull., vol. 49, p. 178, 1938.

[6] *Op. cit.*, p. 168.

A number of minor, discontinuous flexures, with their axes raking in various directions down the dip of the sediments, occur within the Ironwood iron formation. Some of these were apparently caused by slump accompanying the leaching of silica during concentration of the iron formation to ore, and are often localized within and adjacent to the ore bodies. Others may well have developed through secondary deformation during the tilting and faulting of the iron formation.

The basic dikes of the Montreal Mine in the present positions strike for the most part east of north, and the troughs formed by their intersections with the Huronian sediments pitch northeast. However, two important dikes strike north of west, and as a result the troughs formed by their intersections with the Huronian pitch south of west. The general dip of the dikes is roughly normal to that of the sediments.

Faulting.—The most prominent structural dislocation in the Montreal property is the so-called bedding, or longitudinal fault, confined for the most part to the Yale member of the Ironwood iron formation, although it swings locally to cut the upper beds of the Plymouth member, or the lower portion of the Norrie member. In the incompetent Yale slates this fault exists as a zone of rupture in which the slates are much broken and slickensided in various directions. It has been calculated that in the Montreal Mine the strike shift component of displacement along this fault is 800 feet and the dip shift 200 feet, with the hanging, or north, wall moving up and to the east with reference to the foot, or south, wall. This major break was apparently among the earliest dislocations of the iron formation, as it is displaced by the other fault types found in the mine.

Transverse, or oblique faults, usually referred to as cross-faults, are numerous in the mine, transecting the strike of the Huronian beds and the dikes at high angles, and dipping steeply. The majority of these are minor structural features; most of those that cut the Palms formation and the Plymouth member feather out in the Yale slates, as is commonly the case with those found in the Norrie member.

Among the most prominent of the cross-faults is the Bourne fault, which strikes about N. 45° W. and dips almost vertically. The west wall of this fault has moved upward and to the north with reference to the east wall, the strike slip being of the order of 30 to 40 feet, and the dip slip about 10 feet, as far as can be ascertained. The Bourne fault is present in the Palms formation and in the Plymouth member of the iron formation as a zone of brecciation from 1 to 2 feet wide, tightly cemented by vein quartz; it transects the Yale slates and the Norrie member, but in so doing is changed from a single, well-defined dislocation to a number of relatively minor, branching breaks.

A ridge north of Montreal, underlain by basic lavas of the Middle Keweenawan, bears a number of topographic depressions, one of the most pronounced of which is directly in the line of strike of the Bourne fault and is assumed to be reasonably good evidence that the Bourne fault is post-Middle Keweenawan in age. About 10,000 feet east along the strike of the iron formation from the Bourne fault, and near the east end of the Cary property, is the Windsor shear zone. This is a cross-fault containing sheared dike fragments, which strikes rudely parallel to the Bourne fault and dips almost vertically; the west wall has been displaced to the south for a distance of from 70 to 90 feet, with reference to the east wall. The strike of this break is also in line with one of the most pronounced topographic depressions in the Middle Keweenawan trap ridge to the north.

The cross-faults seem to be generally younger than the bedding fault and appear to be of three ages with respect to the time of development of the iron ore bodies. Some were obviously pre-ore, as evidenced by the development of ore bodies where they cut the iron formation. Others were approximately contemporaneous with at least a part of the process of concentration of the iron formation to ore; ore bodies that have not been offset by such faults are found associated with them to a limited extent. Others seem to be post-ore; they either displace the ore bodies in some instances or have not been loci of concentration.

A third variety of structural dislocation is the Gile fault: it

strikes about N. 85° E., and dips north at a low angle. This is a pivotal fault with the pivotal axis located toward the east boundary of the Montreal property; the maximum dip slip seems to be of the order of from 50 to 60 feet, the hanging wall (in the present position of the beds) having moved downward and to the north with reference to the footwall. The Gile fault is believed, but not known, to antedate the Bourne fault; however, both the Gile and Bourne faults were apparently contemporaneous in part with the processes of concentration of the iron formation to ore. The Gile fault is offset by a number of minor, post-ore cross-faults.

Fig. 2 is an idealized illustration of the stratigraphic succession in the Montreal Mine, the relations of the basic dikes to the Huronian sediments, the occurrence of iron ore bodies within the iron formation, and the bedding fault, Gile fault, and Bourne fault.

THE IRON ORE BODIES.

The iron ore bodies of the Montreal Mine are for the most part located in positions in which they would be expected to occur if formed by leaching of the silica of the iron formation and oxidation of any ferrous iron present through the agency of oxidizing solutions possessing an important downward component of movement with respect to the present attitude of the beds. They have been developed in the iron formation either in impervious troughs produced by the intersections of basic dikes with the Palms quartzite or slaty members of the iron formation (trough ore bodies), or at the junctions of pre-ore and co-ore cross-faults with the quartzite or slaty members (chimney ore bodies). The iron-bearing minerals of the ore bodies are dominantly hematite, with locally considerable limonite.*

Most of the iron ore bodies are located in either the Plymouth or Norrie ferruginous chert members of the iron formation. Those occurring south of the bedding fault are called the "foot" ore bodies, and those north of the bedding fault the "hanging"

* Limonite is used as a group name.

ore bodies. In a few instances single ore bodies have extended across the iron formation from the base of the Pence slates to the Palms quartzite, and elsewhere on the range from the top of the Anvil member to the Palms. No commercial ore has been found in the Pabst fragmental horizon in the Montreal Mine, but farther east along the Gogebic range, as in the Pabst and Tilden Mines, well-developed ore bodies were present in this member.

West of the Bourne fault in the Montreal Mine both foot and hanging ore bodies are present; east of it, only foot ore bodies occur in important amounts. Those east of this fault are narrower but much more numerous than those to the west of it.

MANGANESE OCCURRENCES

Manganese Minerals.—The manganese minerals in the Montreal Mine are manganite, pyrolusite, rhodochrosite, and minor amounts of psilomelane. These are found as disseminations in the iron ore; in seams and spottily-distributed, small, irregular masses within the iron ore; as crack-fillings in the chert of the partially-concentrated iron formation adjacent to the iron ore bodies; as vug linings in the ore and iron formation near the ore bodies; and, in one instance, as a fault breccia cement in a post-ore cross-fault near the base of the Plymouth member. Their manner of occurrence leaves little doubt that they were introduced subsequent to the development of the iron ore with which they are associated.

Manganite ordinarily occurs in the iron ore or iron formation as small, well-developed, striated, orthorhombic prisms rarely more than ⅛-inch in maximum dimension. Less commonly it is found in radial fibrous masses, or, in one instance, as an asbestiform lining of a vug in the iron formation.

The pyrolusite observed is present as a black, powdery, often velvety, coating on the manganite aggregates; as such, it is apparently an alteration product of the manganite.

Rhodochrosite in the Montreal Mine has two general types of occurrence in the iron formation and ore; as arborescent aggregates of small, tabular, rhombohedral, pink crystals, in some

cases simulating flos ferri superficially; and as pink, cleavable masses, with characteristic curved surfaces of cleavage, filling cross-fissures up to about 1 inch wide. The fissure fillings observed were characterized by well-developed selvages of talc. In one case crystalline, pink rhodochrosite, showing incipient alteration to manganite, was found as a breccia cement in a cross-fault near the base of the iron formation.

Psilomelane occurs in the iron ore as hard, compact, botryoidal, concentrically-banded masses ordinarily lining the walls of cavities.

Secondary Mineral Associations of the Manganese.—Secondary minerals associated with the manganese minerals are quartz, calcite, barite, celestite, and talc.

Quartz has several types of occurrence. It fills cross-fissures in the Huronian rocks and ore or small slips parallel to the bedding of the Huronian sediments, or it lines the walls of cavities in the iron formation. It may be milky or vitreous. In the cross-fissures and bedding slips it is ordinarily massive, but in a few instances growths of crystals were observed in cross-fissures which were so elongated parallel to the *c* axis as to approach a fibrous condition. In one fissure filling, vitreous quartz crystals were seen to be markedly furrowed parallel to the *c* axis on the prism faces, probably because of mutual interference of the crystals during growth. As cavity linings, the quartz varies from minute, well-developed hexagonal prisms, pyramidally terminated, to distorted crystals whose unequally-developed pyramidal faces are much more pronounced than are the prism faces.

White calcite is present as fissure fillings in cross-fissures and bedding slips in the Huronian rocks, or, in association with the manganese minerals, as cleavable masses of irregular outline with a maximum diameter of about six inches. Yellowish, crystalline calcite may occur with cleavable rhodochrosite filling cross-fissures in the iron ore.

Barite is ordinarily found in cleavable masses, white or pink in color, filling or lining cavities in the manganiferous iron ore. In the Montreal Mine it is in many places coated with the man-

ganese oxides and hydroxides, and apparently preceded them in the sequence of deposition. Although not always accompanying the manganese minerals, the barite, where present, is invariably closely associated with them.

Celestite is rare in the Montreal Mine, but was observed in one instance as small, tabular, orthorhombic crystals partially lining a vug in the Plymouth member of the iron formation near the Palms quartzite. These possessed a bluish tinge and were perhaps ⅛-inch in maximum dimension. Associated with the celestite were small crystals of manganite and quartz.

Talc, as previously mentioned, occurs in well-developed selvages associated with rhodochrosite fillings of cross-fissures in the manganiferous iron ores. It is white when pure, and conforms in physical properties with the usual occurrences of talc; it may be pink where admixed with hematite.

General Distribution of the Manganiferous Ore Bodies—The ore occurrences within the Montreal Mine may be conveniently divided into three groups—the foot ore bodies west of the Bourne fault, the hanging ore bodies west of the Bourne fault, and the foot ore bodies east of the Bourne fault. Of these, the last-mentioned group has produced almost the entire quantity of manganiferous iron ore taken from the property. Recent developments in the lower levels have, however, encountered manganiferous iron ore in relatively small amounts in a hanging ore body about 1,000 feet west of the Bourne fault. Here, the manganiferous ore is associated with a zone of abundant, though minor, cross-fissures and bedding slips in the upper part of the Norrie and near the base of the Pence members.

The confinement of the manganiferous ores almost exclusively to the area east of the Bourne fault is pronounced, and believed to be decidedly significant in any consideration of the origin of these ores. As a broad approximation, it may be stated that the amounts of manganese in the iron ore decrease eastward from the Bourne fault, but manganiferous iron ores extend east into the Cary Mine for a distance of about 1,500 feet from the Montreal east boundary. Other manganiferous iron ores in the Cary

Mine occur in foot ore bodies extending westward for roughly 2,000 feet from the Windsor shear zone. Iron ore is found along the Palms quartzite footwall in limited development east of the Windsor shear zone, but is non-manganiferous.

Manganiferous iron ore has been produced in small amounts from the Bonnie and Eureka Mines, and in relatively large quantities from the Plymouth Mine; these are, respectively, 5 miles, 10½ miles, and 12 miles east of the Montreal Mine along the strike of the iron formation.

Distribution of Manganese in the Ore Bodies.—Examination of all available mine analyses of the manganiferous ore in place reveals that in general the highest concentrations of manganese in the trough ore bodies east of the Bourne fault are located along the quartzite footwall, immediately above the basic dikes, and in the crotches formed by the intersections of these dikes with the quartzite footwall. In the foot chimney ore bodies there is a rather general tendency for the manganese to be localized at or near the contact of these ore bodies with the quartzite footwall.

A foot trough ore body extending across the Bourne fault in the upper mine levels was remarkable for its unusually high manganese content. At the Bourne fault the iron ore in this occurrence contained up to about 20 per cent manganese. This ore body was apparently formed subsequent to the development of the Bourne fault, and is not displaced by this dislocation; it is the only ore occurrence in the mine which is known by direct evidence to have formed subsequent to the time of origin of the Bourne fault.

In the Montreal Mine no marked association of manganese with the upper portions of the trough ore bodies exists. Elsewhere on the Gogebic range, however, such an association is known in some ore bodies, as indicated by Van Hise and Leith.[7]

SALINE WATERS IN THE MONTREAL MINE.

In one of the lower levels in the lower part of the Plymouth member, and close to the east boundary of the Montreal property,

[7] *Op. cit.*, p. 560.

manganese is at present being deposited from solution in saline mine water as pyrolusite, which coats rock fragments, pieces of wood, steel rails, and the walls and floor of this mine opening. A considerable amount of pyrolusite is also found in the waters of the drainage ditches on the floor of the drift. The same conditions exist on a smaller scale in a still lower drift at the base of the iron formation about 1,500 feet east of the Bourne fault. These waters were sampled and partial chemical analyses were made, which indicate them to be of the calcium chloride type. Another partial chemical analysis was made of the mine water in a lower level about 1,000 feet west of the Bourne fault, in an area where manganiferous ore exists in only small amounts; this water was not depositing manganese, and is of the calcium chloride type, but more dilute than the two samples of manganese-depositing saline waters east of the Bourne fault.

These partial analyses (Nos. 3, 4, and 5) are appended (Table 1), together with two complete earlier analyses (Nos. 1 and 2) of Montreal Mine waters from the iron formation in non-manganiferous ore territory about 4,300 feet west of the Bourne fault. For comparison, analyses of calcium chloride waters from other parts of the Lake Superior district are also indicated.

Because this type of mine water is now transporting and depositing manganese in the Montreal Mine, because it is widespread in the Lake Superior region, and because it has received considerable attention in the past, an examination of some of the facts of its occurrence is perhaps advisable.

In the writer's opinion, it is more than a coincidence that the analyses given, taken from over a considerable area in the Lake Superior district, are strikingly similar in the proportions of the major constituents, except in the waters from the Republic and Silver Islet mines (Nos. 7 and 10), which contain relatively more sodium than the others. The principal variations seem to be for the most part due merely to varying degrees of dilution. The similarity in composition over a broad area of these somewhat unusual waters suggests that they developed under parallel con-

TABLE 1.

TABLE 1.

ANALYSES OF WATERS.

	1	2	3	4	5	6	7	8	9	10
Cl	1,032	1,076	3,380	3,420	1,710	11,431	25,360	134,916	13,960	22,165
CO_3						6.9				
HCO_3	123	120				91.2				
CO_3								21		173
NO_3	17.7	14.2				trace				
PO_4	1.7	0.7								
SO_4	14.4	13.5	96	90	57	256.6	1,045	21		47
SiO_2	9.5	9.8				11.1		21		54
Ca	398.6	402.3	1,360	1,530	740	4,164.5	7,902	65,346	4,477	6,286
Mg	119.4	124.8	136	121	68	647.8	566	21	921	436
Na	102	105				} 1,673.7	} 7,290	11,952	1,887	6,599
K	11.7	10.7							416	241
Al	0.55	1.5				} 4				
Fe	1.3	0.63	trace	0.5	trace					
Al_2O_3							} 700			
Fe_2O_3										
Mn	2.4	2.2	7	7						

1. From drill hole in Norrie member, 4,300 ft. W. of Bourne fault, 23rd level, Montreal Mine.
2. From drill hole in Plymouth member, 4,300 ft. W. of Bourne fault, 23rd level, Montreal Mine.
3. From 27th level in Plymouth member, 3,800 ft. E. of Bourne fault, Montreal Mine.
4. From 34th level in Plymouth member, 1,500 ft. E. of Bourne fault, Montreal Mine.
5. From 30th level in Plymouth member, 1,000 ft. W. of Bourne fault, Montreal Mine.
6. From 28th level in Plymouth member, Eureka Mine, Ramsay, Michigan.
7. From 17th level, Republic iron mine, Michigan. A. C. Lane, Mine waters, 13th Ann. Meet., Lake Superior Min. Inst., 1908, p. 31.
8. From lower level, Quincy copper mine, Hancock, Michigan. Data of Geochemistry, 1924, p. 187.
9. From well 192 feet deep, Manitoulin Island, Lake Huron. Chem. and Geol. Essays, 1875, p. 158.
10. From Silver Islet Mine, Lake Superior. Ann. Rept. Geol. Surv. Can., new series, vol. 1, 1885, p. 17M.

Analysts: 1–2, H. A. Schuette, Univ. of Wis., 1923; 3–5, U. S. Bur. Mines, 1936; 6, R. S. McPherran, 1932; 7, C. Fernekes, 1908; 8, G. Steiger; 9, T. Sterry Hunt, 1875; 10, F. D. Adams, 1885.

ditions, or perhaps offers some support to the hypothesis that they may have been derived from the same source.

Lane [8] has stated his belief that the calcium chloride waters probably represent connate sea waters, although they are decidedly different in composition from any sea waters known to exist at present.

Van Hise and Leith [9] suggest that they are stagnant meteoric waters which have become enriched in soluble salts derived from the iron formation, and which, because of their sluggish flow, have been unable to remove completely these salts in solution. This concept that the calcium chloride waters in the iron mines are stagnant or ponded meteoric waters had led in some quarters to the belief that where present they are representative of conditions unfavorable to the formation of iron ore bodies. In this regard it may be noted that waters of this type are abundant in the Montreal Mine, but no apparent relationship exists between presence or absence of iron ore and corresponding absence or presence of calcium chloride waters. Similarly, there appears to be no relationship between the presence of calcium chloride waters and the presence of manganiferous iron ores; the saline waters occur in both manganiferous and non-manganiferous ore territories. At some place in the manganiferous regions they transport manganese in solution, and not at other points in the same area. Although space does not permit a detailed presentation of the facts, it may be stated that in the Montreal property at the present time the calcium chloride waters are found in localities that are apparently largely protected by certain geologic structures or dike occurrences from invasion by waters moving downward from the present ground surface. For instance, the mine water from above one of the uppermost dikes east of the Bourne fault was formerly used as a source of the local water supply; below this dike the mine water is, as far as could be discovered, saline and not potable.

[8] Lane, A. C.: Calcium chloride waters, connate and diagenetic. Amer. Assoc. of Petr. Geol. Bull., vol. 11, pp. 1283–1305, 1927; and other papers.

[9] *Op. cit.*, p. 544.

POSTULATED ORIGIN OF THE MANGANESE.

Any hypothesis that seeks to explain the origin of the manganiferous iron ores of the Montreal Mine must account for (1), the remarkably high manganese content of the single ore body that extends across the Bourne fault, (2), the marked confinement of the manganiferous ores to the part of the property located east of the Bourne fault, (3), the presence of both rhodochrosite and manganic oxides and hydroxides, (4), the observed fact that the manganese minerals were introduced into the iron ore bodies subsequent to the development of these ore bodies, and (5), for the general localization of the manganese minerals in the trough ore bodies adjacent to their contacts with the dikes and quartzite footwall and in the chimney ore bodies adjacent to the quartzite footwall.

The hypothesis favored by the writer is, briefly, that most of the manganese was introduced into the iron ore bodies by solutions that ascended principally along the Bourne fault from a deep-seated igneous source, migrated for the most part laterally through the ore bodies east of this fault, and eventually made their way up the dip of the iron formation through chimney ore bodies and along minor, post-ore cross-faults. The Windsor shear zone in the Cary Mine is believed to have functioned in the same manner in regard to manganese mineralization as did the Bourne fault, but to a lesser degree.

The pronounced manganese content of the ore body extending across the Bourne fault indicates strongly that, since the ore body was formed subsequent to the development of the Bourne fault, the manganese-bearing solutions utilized this fault as a major avenue of migration.

The striking confinement of the manganiferous ores in the Montreal Mine to foot ore bodies east of the Bourne fault is believed to be due to the combined effects of four major factors. The first of these is that, if the Bourne fault is pictured as having developed at a time when the iron formation was tilted at a relatively low angle rather than at its present steep inclination, the part of the Montreal Mine that is located east of the fault would

have constituted the down-dropped wall. If the manganese-bearing solutions are visualized as having risen along the Bourne fault, the first contact of these solutions with the previously-formed iron ore bodies, which were doubtless more permeable than the adjacent rocks, would have taken place upon their encountering those ore bodies located on the down-dropped side of the fault. For this reason alone it is probable that a major part of the manganese-bearing solutions would have entered the ore bodies east of the fault rather than those located on the west, or upthrown, side of the break. During the passage of the manganese-bearing solutions through the ore bodies and iron formation, the precipitation of manganese, probably as rhodochrosite, took place.

The second factor is that, whereas six important foot trough ore bodies east of the Bourne fault either reach this fault or approach it closely, only one large foot trough ore body west of the Bourne fault extends eastward to the dislocation. From this it is apparent that manganese-bearing solutions could have moved eastward from the Bourne fault through six major foot trough ore bodies and their connecting ore chimneys, but would have had access to the territory west of the fault through only one such ore body. The implications of this fact as regards the manganese distribution are obvious.

Third, the foot ore bodies west of the Bourne fault are generally much wider than those to the east of it. Consequently, a given volume of manganese-bearing solutions would have been dispersed through a greater volume of iron ore in a single ore body west of the Bourne fault than would an equivalent volume of the solutions in a foot ore body of comparable dimensions along dip and strike east of the fault. Given two ore bodies of the same footwall area, which received identical quantities of manganese, the weight per cent of manganese in the wider ore body would obviously be less than in the narrower one, other conditions being equal. The effect of narrowing of the ore bodies upon their manganese content is well-shown in an extensive chimney ore body located between the Bourne fault and the east bound-

ary of the Montreal property; the constricted portions of this ore body are noticeably higher in manganese than are its wider parts.

Fourth, the splitting of the Bourne fault into a series of minor ruptures in the incompetent Yale slates and in the Norrie member may be regarded as a prominent reason for the low manganese content of the hanging ore bodies in the Montreal Mine. Any part of the manganese-bearing solutions that escaped being tapped from the Bourne fault by the foot ore bodies would have moved upward to the junction of the fault with the Yale slates and there encountered considerable difficulty in making its way through these slates into the Norrie member. That a small portion of the solutions perhaps succeeded in doing so is evidenced by local, subordinate spots of manganiferous iron ore in the hanging ore bodies near the Bourne fault. The remainder of the manganese-bearing solutions, failing to penetrate the Yale slates, would have moved upward along the contact of the Bourne fault with the base of these slates until they passed from the area of that part of the entire picture now represented by the Montreal Mine.

The relations of manganese to the Windsor shear zone in the Cary Mine are in general agreement with this hypothesis. The manganiferous iron ores extend west from the shear zone for some distance along the quartzite footwall; the west side of the dislocation represents what would have been the downdropped wall with the beds in a slightly-tilted position. Non-manganiferous iron ore is present east of the shear zone, but is relatively poorly-developed. No hanging ore bodies are known to be present in the Cary Mine.

The hypothesis that manganese was contributed to the iron ores of the Montreal Mine by solutions ascending from a deep-seated igneous source rests largely upon the distribution of the manganese rather than upon the nature of the minerals themselves. Gruner,[10] however, has identified magnesiosussexite in a specimen taken from a manganiferous iron ore area in the Eureka Mine; it is stated to be of hydrothermal origin and to have the composition $2(Mg, Mn)O.B_2O_3.H_2O$. The rare manganese

[10] Gruner, J. W.: Magnesiosussexite, a new mineral from a Michigan iron mine, isomorphous with sussexite and camsellite. Am. Mineral., vol. 17, pp. 509–513, 1932.

mineral neotocite has also been found in the Eureka Mine; it is usually regarded[11] as developing through the hydration of rhodonite. Broderick[12] has found small amounts of manganite with barite in the lower workings in the Calumet and Hecla conglomerate, where copper and its associated minerals are generally believed to have been of hydrothermal derivation.

In addition, there is widespread evidence on the Gogebic range of what appears to have been late pre-Cambrian hydrothermal mineralization. For instance, a few crystals of native copper have been collected from the Plymouth member near its base in the Cary Mine, and Scofield[13] has noted the following metallic sulphides, in order of relative abundance, in the basal conglomerate of the Palms quartz slate, overlying granite unconformably in the Newport Mine: galena, pyrite, chalcopyrite, bornite, pyrrhotite, molybdenite, and sphalerite. The writer has observed, in the Eureka Mine, local concentrations of pyrite and chalcopyrite associated with vein quartz in the immediate vicinity of an unconformable surface of contact between granite and the Palms quartz slate; here the pyrite bears traces of gold. In the Montreal Mine a small vug lined with galena was found near the top of the Palms quartzite on the 27th level. Although not in any way a decisive criterion, the Tyler slate north of the Montreal property is cut locally by numerous quartz veins.

The hypothesis that the iron ore bodies were originally developed by solutions that possessed an important downward component of movement with respect to the present attitude of the rocks, and which were concentrated in their passage through the iron formation at the junctions of cross-faults with impervious beds, and in troughs formed by the intersections of basic dikes with impervious beds within and underlying the iron formation, seems necessary to an explanation of the distribution of manganese within the ore bodies. According to this hypothesis, the most permeable portions of the iron ore bodies would have been

[11] Dana, E. S. and Ford, W. E.: A text-book of mineralogy. 3rd edition, pp. 485, 582, 1922.

[12] T. M. Broderick, personal communication.

[13] Atwater, G. I.: *Op. cit.*, p. 187.

adjacent to the quartzite footwall in the chimney ore bodies and in the trough ore bodies in those parts that are located just above the dikes, along the footwall, and in the crotches formed by the intersection of the dikes with the footwall. These areas within the ore bodies, being the most permeable, would have been the areas through which the manganese-bearing solutions migrated in greatest volume; it is in these portions of the Montreal ore bodies that the highest concentrations of manganese are now found. Elsewhere on the Gogebic range, the occurrence of a relatively high content of manganese in the upper parts of the trough ore bodies and adjacent to the capping of the chimney ore bodies may be explained by the development of unusual permeability through slumping of the ore downward away from the iron formation capping as the concentration proceeded. Consequently, those portions of the ore bodies adjacent to the capping would have been pervaded by the manganese-containing solutions with greater readiness than the inner, more impermeable zones.

The presence of rhodochrosite associated with talc in cross-fissures in the ore bodies indicates that the manganese was in part contributed by solutions migrating along a number of minor dislocations as well as along the Bourne fault. It must be assumed, however, from the facts of manganese occurrence, that in the Montreal Mine the Bourne fault was utilized by these solutions as the principal channel of upward movement.

The hypothesis of secondary introduction of manganese into the iron ore bodies by ascending solutions does not exclude the possibility, even probability, that some manganese was incorporated in the iron formation during primary sedimentation. All available analyses of the Plymouth member of the iron formation in the Montreal Mine show an average of 0.4 per cent manganese; since most of the analyzed samples were taken from partially-leached iron formation adjacent to the ore bodies, it seems likely that what might be referred to as the "normal" manganese content of the Plymouth member is less than this amount.

The association in the same ore bodies of rhodochrosite and the manganic oxides and hydroxides is, in the writer's opinion,

incompatible with any concept of roughly simultaneous precipitation of these minerals from either a single solution or a single type of solution. Hewett and Pardee,[14] found somewhat similar circumstances in manganese-bearing regions of Washington, Oregon, and California, and concluded that in those areas manganese oxides, silicates, and hydrous silicates resulted from alteration of pre-existing manganese carbonates by circulating hot waters related to igneous intrusions.

It might be suggested that downward-moving waters that are usually regarded as having accomplished the concentration of the iron formation to ore may have eventually effected the transportation of the manganese. A large part of these waters, originally oxidizing in nature, would have become saturated with CO_2 as any siderite present in the iron formation was altered to hematite and limonite. Such waters might conceivably have leached the manganese from the iron formation and carried it as the soluble bicarbonate not only downward but laterally at depth until the Bourne fault was encountered, whereupon they might be regarded as migrating upward and penetrating the iron ore bodies, with a resultant deposition of the manganese as rhodochrosite. This hypothesis is not regarded as plausible for several reasons.

There is no evidence, in the mine analyses, of extensive removal of manganese in solution from the iron formation. In general, the greater the amounts of leaching of the iron formation in the "non-manganiferous" areas, the higher is its manganese content; this condition does not suggest abstraction of the manganese in solution. No good reason presents itself for the Bourne fault having been an avenue of upward, rather than downward, movement of such waters. Further, by nature of the postulated process of concentration of the iron formation to ore, saturation of the waters with CO_2 would have been most marked in the early stages of development of the ore bodies, rather than in the later stages, when most of the siderite would have been already altered to hematite and limonite. Consequently, waters

[14] Hewett, D. F. and Pardee, J. T.: Manganese in western hydrothermal ore deposits. Ore Deposits of the Western States, A. I. M. M. E., p. 682, 1933.

capable of transporting manganese in relatively large amounts as the bicarbonate would have been early developments in the concentration sequence. This is not in agreement with the observation that manganese was introduced into the iron ore bodies after they had attained approximately their present dimensions.

Relation of the Saline Waters to Manganese Occurrences.

In the writer's opinion, the very general occurrence in the Montreal Mine of manganite, psilomelane, and pyrolusite as vug and cavity linings in the iron ores, together with observed incipient alteration of rhodochrosite to manganite, suggests that the oxides and hydroxides have resulted from oxidation of rhodochrosite, presumably the form in which the manganese was deposited in the iron ores. The agent of alteration is thought to have been solutions bearing calcium chloride as a prominent constituent.

DeWitt[15] has found that water solutions of calcium chloride are capable of dissolving only very small amounts of rhodochrosite, even though the reaction mixture is heated for a long time at the boiling point of the solution. If, however, SO_2 is introduced into the solution, the manganese carbonate dissolves rapidly, and in the presence of oxygen the following reaction apparently takes place:

$$MnCO_3 + CaCl_2 + H_2SO_3 + O \rightarrow MnCl_2 + CaSO_4 + H_2CO_3$$

A reaction of this nature would explain reasonably the origin of the calcite, barite, and celestite which are associated with the manganese oxides and hydroxides. Presumably the calcium sulphate formed would react with the carbonic acid to yield calcite; Scofield,[16] however, has noted small amounts of gypsum in the iron formation of the Cary Mine. If barium or strontium chlorides were present, barite or celestite would be produced instead of calcium sulphate. The $MnCl_2$, in calcium chloride solution containing dissolved oxygen, alters rapidly to the hydroxide;

[15] DeWitt, C. C.: Leaching ore. U. S. Patent No. 1,835,474, 1931.

[16] Scofield, L. M.: Personal communication.

this is readily confirmed by experiment. As suggested by Trengove,[17] water vapor at elevated temperatures may have accomplished, by direct oxidation, a major portion of the alteration of the rhodochrosite.

The DeWitt reaction is not at variance with the observed mineral associations in the manganiferous iron ores. It suggests, though of course does not prove, that SO_2 was an original constituent of the calcium chloride solutions. If so, a juvenile origin might well be indicated for these solutions.

That the calcium chloride and associated soluble salts were products of primary sedimentation during deposition of the iron formation is doubtful, in view of the wide distribution of these materials in both sedimentary and igneous rocks of different ages in the Lake Superior region, and the improbability that these soluble substances could have remained in the ore bodies and associated iron formation throughout the ore concentration sequence. It is suggested that calcium chloride, with other salts now present in the mine waters, was contributed to the iron formation and ore by solutions of juvenile origin, following the introduction of manganese; these solutions might well have been the principal factor in the oxidation and hydration of previously-formed rhodochrosite. It may be that calcium chloride and its accompanying salts were contributed directly to waters in the ore bodies and iron formation, rather than having been first precipitated as a solid and later taken into solution. Regardless of whether these salts were contributed to the iron formation and ore as sublimates or whether they were added to waters already present in the iron formation and ore bodies, they have since migrated for considerable distances by diffusion in solution, or were not influenced in their distribution by the same structural factors that localized the deposition of the manganese.

If the prominent constituents of the saline waters are of juvenile origin, it is not known whether they were late phases of the same period of igneous activity which seems to have been responsible for the presence of the manganese in the iron ores, or

[17] *Op. cit.*

whether they were connected genetically with a still later intrusion.

Age and Source of the Manganese Mineralization.

The age and source of the manganese mineralization, if ultimately of igneous derivation, are not precisely known. The Bourne fault is probably post-Middle Keweenawan; although there are evidences of post-Cambrian faulting in places on the south shore of Lake Superior, and, as at Limestone Mountain, of post-Devonian faulting and folding, it has yet to be demonstrated that igneous intrusion was associated with such deformation. Consequently, it is believed that the manganese was brought into the iron ores during post-Middle Keweenawan, pre-Cambrian time, and subsequent in large part to the complete development of the iron ore bodies. The Killarnean granite known to exist elsewhere in the general area is of this age; it may well be that this intrusive exists at some depth beneath the Montreal Mine.

SUMMARY.

Most of the manganese in the iron ore bodies of the Montreal Mine is believed to have been contributed to these ores from a deep-seated igneous source by solutions rising principally along a post-Middle Keweenawan, pre-Cambrian dislocation known as the Bourne fault. The manganese is considered to have been first deposited as rhodochrosite, which was later oxidized in large part and to some extent redistributed by calcium chloride solutions, which are suggested to have been ultimately of juvenile origin. The manganese was selectively introduced into relatively permeable portions of the iron ore bodies east of the Bourne fault after these ore bodies had attained essentially their present dimensions. It may reasonably be assumed from the manganese occurrences that the manganese-bearing solutions rose along the Bourne fault when the Ironwood iron formation and the iron ore bodies were at most in only a slightly-tilted position, rather than in their present attitude.

ACKNOWLEDGMENTS.

The writer is greatly indebted to Mr. L. M. Scofield, for a number of years geologist for Pickands, Mather and Company and now geologist for the Calumet and Hecla Consolidated Copper Company, for first suggesting the possibility of a hydrothermal source of the manganese, and for pointing out the prominent association of manganese with areas of theoretically greatest permeability in the iron ore bodies; he has also contributed much to the content of this paper through numerous verbal discussions, as has Dr. T. M. Broderick, chief geologist of the Calumet and Hecla Consolidated Copper Company.

Mr. L. E. Dick, chief engineer for the Montreal Mining Company, has been of the greatest assistance during the course of the investigation, as have Mr. O. M. Schaus, general superintendent of the Montreal Mining Company, and the other officials and members of the engineering staff of that organization. Mr. R. C. Allen and Mr. V. D. Johnston, of Oglebay, Norton and Company have read the manuscript critically and offered a number of suggestions, and it is with their permission and that of the Montreal Mining Company that the results of the study are published.

MICHIGAN COLLEGE OF MINING AND TECHNOLOGY,
HOUGHTON, MICHIGAN,
May 11, 1938.

A "RED BEDS" TYPE COPPER OCCURRENCE, WYOMING CO., PENNSYLVANIA.

ROBERT D. BUTLER.

ABSTRACT.

Two small exposures of copper minerals in Catskill rocks of Devonian age in Wyoming Co., Pa., show mineralization of gray sandstones and shales intercalated with red strata. One prospect contains compressed and mineralized plant remnants that are semi-bituminous or anthracite in rank. Epigenetic minerals are bornite, blue and white chalcocite, and chalcopyrite. Cracks in the altered plant remnants are filled by bornite. Good preservation of cell structures probably is due to replacement of cell interiors by bornite and chalcocite. The evidence indicates that the mineralization occurred subsequent to metamorphism, and therefore it could not have occurred immediately after or accompanying the burial of the plants.

INTRODUCTION.

Copper carbonates and silicates in thin films along bedding and joint planes of sandstone and shale are not uncommon in Pennsylvania and have been reported in upper Devonian rocks at several places. In some of these, the copper minerals are associated with carbonized plant remains; chalcocite has been found at a few localities.[1] These deposits are not of economic importance although one shipment of 2½ per cent copper ore is said to have been made from the Carpenter mine, near New Albany, Bradford County. In New Jersey, the Pahaquarry mine, near the Delaware Water Gap, is of the same type but the minerals are contained in sandstones of Silurian age.[2] This mine was first worked by the early settlers of the region.

Similar deposits are found in many places in the southwestern states and are called the "Red Beds" type because of their com-

[1] Weed, W. H.: Copper deposits of the Appalachian States. U. S. Geol. Surv. Bull. 455, pp. 59–61, 1911.

[2] Weed, W. H.: *Op. cit.*, pp. 54–57.

mon association with red sedimentary rocks of clastic continental origin. It has been found, however, that although the rock series in which they occur are classed as "Red Beds," the copper minerals themselves seldom are in red strata.[3] The enclosing rocks of these deposits in the southwestern states are of Permian, Triassic, or Jurassic age. Lindgren,[4] Bastin,[5] Finch,[6] and Fischer [7] cite the literature on U. S. and foreign occurrences.

LOCATION AND DESCRIPTION.

Two occurrences of copper minerals have been found in road cuts near Forkston, a hamlet seven miles west of Mehoopany, Wyoming County. About 200 yards north of the Forkston crossroads, a small niche has been dug in the side of a road cut. Several thin beds of gray sandstone and shale aggregating about 4 feet in thickness lie horizontally between brownish red sandstones and shales of the Catskill facies. Thin carbonized films show remnants of plant fossils and the gray strata contain seams of malachite and patches of azurite along small joints and bedding planes. The green copper coloration is more pronounced at the bottom of this 4-foot thickness of gray beds. The copper stains disappear 20 feet to the south but their northward extent is obscured.

The other occurrence is about 300 yards south of Forkston along a road cut above Mehoopany Creek. It is hidden (March, 1938) by slumping of soil but a pile of copper-stained shale lies nearby. This occurrence differs from the other in that bornite and chalcocite are associated with compressed and carbonized plant remains. The enclosing rocks are grayish-green shales and sandy shales overlying red sandstones and shales that are well-

[3] Finch, J. W.: Sedimentary copper deposits of the Western States. Ore deposits of the Western States, p. 482, New York, 1933.

[4] Lindgren, W.: Mineral deposits, 4th ed., pp. 403–409, New York, 1933.

[5] Bastin, E. S.: The chalcocite and native copper types of ore deposits. ECON. GEOL., vol. 28, pp. 407–446, 1933.

[6] Finch, J. W.: *Op. cit.*, pp. 481–487.

[7] Fischer, R. P.: Sedimentary deposits of copper, vanadium-uranium, and silver in southwestern United States. ECON. GEOL., vol. 32, pp. 906–951, 1937.

exposed along the stream. The sulphides are confined to several narrow bands aggregating a few inches in thickness through a vertical interval of about two feet. Malachite occurs along joints and bedding planes of the shale and as thin crusts upon plant remains.

Although not verified by the writer, it appears probable from statements by the owner of the prospects, Mr. J. W. Lott, that the several narrow bands contain all the visible plant remains as well as all the copper sulphide. Specimens studied indicate that the copper sulphides preferentially deposited in plant remains and are not present in other associations.

Plant remains consist of compressed fragments of branches or roots. Their lengths range from 2 to 5 inches; the longer cross-sectional diameters range from 1½ to 3 inches, the shorter from ½ to 1 inch. Identification of the plants is impossible.

It is extremely improbable that this deposit could ever be worked because of the small quantity of copper minerals, although individual specimens are rich in copper. In 1883, I. C. White noted the occurrence of copper in Catskill rocks in Nicholson Township, Wyoming County, and said "Slight traces of copper, lead and nickel and sometimes zinc are found . . . but always in such minute quantities that mining can never be profitable . . . no genuine fissures have ever been found penetrating these beds; and from the facts in hand are very unlikely ever to be found." [8]

ANALYSES.

A specimen of the cupriferous plant material was finely ground and the carbonaceous matter separated by zinc chloride flotation. Professor Eric Sinkinson analyzed the material and found 13.5 per cent volatiles. The sample was too small for accurate identification but the analysis indicates the material is not lignite. He states that the carbonaceous material is non-coking and is either semi-bituminous or anthracite in rank.

Spectroscopic analyses have been made of the cupriferous plant

[8] White, I. C.: The geology of the Susquehanna River region, Pa. 2d Geol. Surv., Rept. G7, p. 129, 1883.

material and the copper-stained shale. Besides elements that can be ascribed to visible ore and rock minerals, manganese, titanium, silver, vanadium, molybdenum, and chromium are present in minor amounts. Lindgren records these elements as well as uranium, lead, barium, nickel, cobalt, and selenium from "Red Beds" type deposits.[9]

The owner reports assays of gold and silver.

MICROSCOPIC DESCRIPTION.

Polished surfaces show bornite, blue and white chalcocite, altered plant material, chalcopyrite, and covellite. The cellular aspect of the copper minerals testifies as to the organic nature of the original material.

Remnants of plant material are widely distributed throughout the specimens but are small in total amount. The altered plant material is in extremely irregular bands, for the most part parallel to the longer cross-sectional axis of the specimens. Zones of remnants are found between bands. The plant material displays a tan color under reflected light and is anisotropic between crossed Nicols with extinction directions nearly parallel to the long and short cross-sectional axes of the specimens. Remnants within any one microscopic field extinguish in the same position, although here and there traces of undulous extinction can be seen. Fig. 1 shows a portion of one of the bands of plant material. Structures of the plant remains could not be developed by chromic acid or flame etch, and are not visible in thin section.

Bornite and chalcocite are present in about equal quantities and comprise the main part of the specimens. Chalcopyrite and covellite occur in truly minor amounts.

Most of the bornite occurs pseudomorphic after the cell structure (Figs. 2 and 4) but some is observed in irregular masses or in graphic intergrowths with chalcocite (Fig. 3). Where bornite occupies cell interiors, the cell walls are either residuary plant material or chalcocite. Some former cells are composed of a central

[9] Lindgren, W.: *Op. cit.*, pp. 403–409.

core of bornite surrounded by a narrow rim of chalcocite, in turn bordered by altered plant material at the margins of the original cell. Irregular masses of bornite without inherited cell structure are present here and there throughout the specimens. Numerous seams in the carbonaceous material are occupied by bornite, chalcocite, or both. These have matching walls and are larger and more abundant normal to the longer cross-sectional axes of the compressed plant remains.

Blue and white varieties of chalcocite are present. Both yield an orthorhombic etch pattern and react differentially with reagents, especially potassium cyanide. Blue chalcocite is found in cell interiors as is bornite, and in narrow rims around bornite cell structures. Bundles of cells consist either entirely of blue chalcocite or dominantly of bornite with subordinate blue chalcocite. Partial replacement of cellular bornite by blue chalcocite is common. A very small proportion of the white chalcocite displays inherited cellular structure. It is, however, typically observed surrounding cell structures of blue chalcocite, in irregular masses, or graphically intergrown with bornite. Veinlets and irregular masses transect bornite, blue chalcocite, and altered plant remnants. Both types of chalcocite are present in veinlets that cut plant remains. These veinlets display matching walls in many places with connected irregular replacement masses here and there. In all respects, such veinlets are similar to the previously mentioned veinlets of bornite, and indeed, in most cases the two minerals are found together in the veinlets.

Chalcocite with inherited cell structure displays upon etching a random distribution of grains. Average grain size is in the order of 0.01 mm. In only one of the many cell cross sections that have been etched does chalcocite show directional crystallization with respect to cell walls. In this case the row of grains adjacent to the cell wall is normal to it but grains in the cell interior have random orientations. Neighboring cells show no signs of directional arrangement. Some small lenticular chalcocite masses do not have inherited cell structure but show crystallization perpendicular to the long axis of the mass. The length of single crystals spans the thickness of such masses.

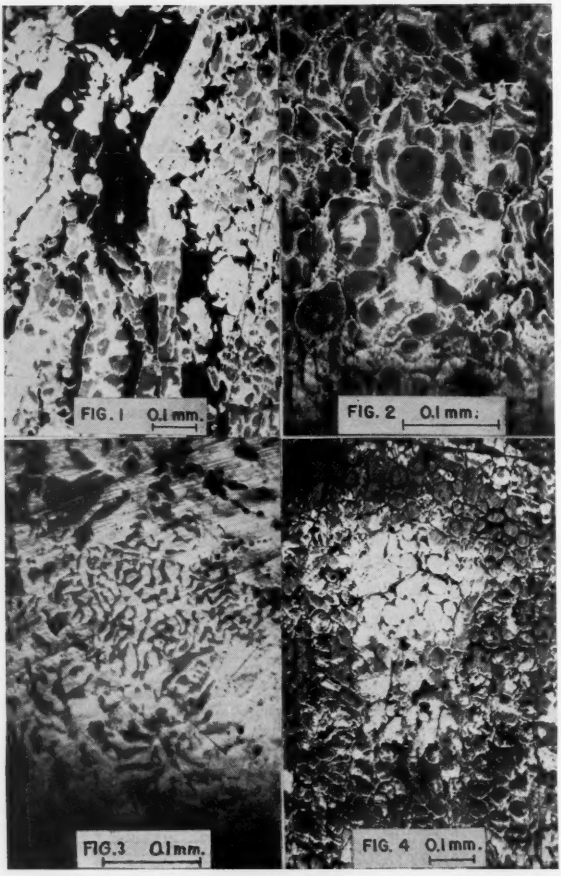

FIG. 1. Portion of an irregular band of plant material (black) veined and replaced by bornite (gray) and chalcocite (white). Note narrow gash veinlets. × 70.

FIG. 2. Cell structure of plant material inherited by bornite (gray). Chalcocite (white) formed around cell edges and replaced interiors of cells containing bornite (center), × 150.

Chalcopyrite occurs within bornite at contacts with blue chalcocite. The tiny areas of chalcopyrite are few, irregular in outline, and the largest diameter is 0.01 mm.

A few tiny areas of covellite were observed in chalcocite adjacent to minute cracks.

DISCUSSION.

In accounting for the origin of this deposit, the following evidence must be considered:

1. *Field.*—Horizontal Devonian strata; copper minerals in fractured sandstones and shales intercalated with "Red Beds"; no apparent fissures; numerous seams containing malachite; absence of igneous rocks; observations scanty.

2. *Megascopic.*—Sulphides contained in compressed fossil plant remnants; remnants have cross-sectional diameters, 3:1.

3. *Analytic.*—Plant remains are high rank coal; spectroscope shows presence of silver, vanadium, molybdenum, and chromium, which are common "Red Beds" elements; gold is reported.

4. *Microscopic.*—Bornite and two kinds of chalcocite prominent; plant remains show numerous fractures with matching walls which contain sulphides; cell structures well-preserved; some replacement of plant remains.

The plant remains were compressed and metamorphosed into a high rank member of the coal series before introduction of the mineralizing solutions. Hess,[10] David White,[11] and later, Fischer,[12] point out that the general absence of deformation, both internal and external, of mineralized plant remnants in deposits in the southwestern United States is indicative of mineralization

[10] Hess, F. L.: Hypothesis for the origin of the carnotites of Colorado and Utah. ECON. GEOL., vol. 9, p. 681, 1914.

[11] White, D.: Discussion. A. I. M. E. Tr., vol. 76, p. 385–386, 1928.

[12] Fischer, R. P.: *Op. cit.*, pp. 918–945.

FIG. 3. Graphic intergrowth of bornite (gray) and white chalcocite (white). × 150.

FIG. 4. Cell structure inherited by both bornite (dark gray) and blue chalcocite (white). Altered plant material (black) rims most of the cells. × 70.

before deep burial or appreciable metamorphism. With the exception of Papenfus, writers have usually referred to altered plant remains as lignite. Papenfus shows pyrite and blue chalcocite pseudomorphic after woody material in a Nova Scotian deposit and considers that further metamorphism intervened before deposition of white chalcocite.[13] As the second generation chalcocite does not preserve cell structures, he considers it was deposited after metamorphism of the plant remains to coal.

In the present case the observations suggest the conclusion that the plant material had been metamorphosed before mineralization. The deforming factor was the load of superimposed sediments, and compressed fossil branches or roots were produced. There are microscopic fragments and numerous cracks with matching walls that formed in consequence of compression, and all the minerals occur surrounding fragments, as fillings, or as replacements of fillings. Irregular areas of bornite surrounded by chalcocite in many cracks indicates that the earliest mineral, bornite, was formerly present in greater amount and occupied cracks due to compression.

The internal deformation of the plant fragments took place, not by collapse of cell walls but by bending, slumping, and minute fracturing of comparatively large bundles of cells. It is probable that partial decomposition of the entombed plants created weaker zones that allowed this type of deformation to proceed without affecting cell walls of less decomposed portions. Turner,[14] and Thiessen and Sprunk[15] show photomicrographs of bituminous coals and anthracite in which the cell structures are not appreciably distorted, indicating that metamorphism is not everywhere accompanied by such deformation.

There is no evidence of deformation subsequent to formation of the minerals. Recrystallization could have destroyed such

[13] Papenfus, E. B.: "Red Bed" copper deposits in Nova Scotia and New Brunswick. ECON. GEOL., vol. 26, pp. 318–321, 1931.

[14] Turner, H. G.: Microscopical structure of anthracite. A. I. M. E. Tr., vol. 71, pp. 127–148, 1925. Constitution and nature of Pennsylvania anthracite with comparisons to bituminous coal. A. I. M. E. Tr., Coal Division, pp. 627–643, 1930.

[15] Thiessen, R., and Sprunk, G. C.: Microscopic and petrographic studies of certain American coals. U. S. Bur. Mines Tech. Paper 564, 1935.

evidence, of course, but should have left clues to its former activity.

The origin of this deposit is amenable to the generalizations of Lindgren,[16] Rogers,[17] and Bastin [18] that concentration of copper from cupriferous meteoric solutions could have occurred at any time after the entombment of the plants. As metamorphism preceded mineralization, the depositing solutions must have gained access long after burial.

Filling of open cracks in the carbonized remnants by bornite was an important feature of the sulphide mineralization. Some replacement can be shown adjacent to these cracks but a problem is attached to the question whether preservation of cell structure is due to filling or to replacement. Fischer stresses filling as the responsible process;[19] other authors have ascribed it to replacement. In this case numerous indirect arguments can be sought which support the replacement hypothesis but none is conclusive.

The chalcocite stages of deposition were characterized by replacement of bornite, although it is an open question as to whether some groups of chalcocitized cells are due to complete replacement of bornite, replacement of cell interiors, or filling of cell interiors. It is certain, however, that white chalcocite replaced both bornite and blue chalcocite.

Malachite and azurite are ascribed to recent meteoric activity. Shells of malachite encase the mineralized fragments and narrow transverse seams on the exterior of the specimens contain bornite and chalcocite that have been partially altered to malachite. The distribution of covellite in the specimens suggests a similar origin.

SUMMARY.

The enumerated points present many features common with the "Red Beds" type copper deposits of the southwestern United States and elsewhere and, likewise, a satisfactory explanation for

[16] Lindgren, W.: *Op. cit.*, p. 404.

[17] Rogers, A. F.: Origin of copper ores of the "Red Beds" type. ECON. GEOL., vol. 11, p. 380, 1916.

[18] Bastin, E. S.: *Op. cit.*, pp. 418–419.

[19] Fischer, R. P.: *Op. cit.*, p. 918.

the origin is difficult to formulate. It would be unwise in the present instance to generalize on the method of transport of the copper because of lack of field data but the microscopic observations are sufficiently at variance with other localities to warrant modification of recently advanced theories in order to account for this deposit.

The relations indicate the following:

1. Compression and metamorphism of entombed plant remains to high rank coal.
2. Introduction of copper, iron, and sulphur to form bornite. Filling of cracks in the coalified remnants and filling or replacement of cell interiors occurred.
3. Replacement of bornite by blue chalcocite, replacement of cell walls by blue chalcocite, and replacement or filling of cell interiors by blue chalcocite occurred. Blue chalcocite filled cracks in altered plant material. Chalcopyrite formed at this stage in consequence of incomplete removal of iron.
4. Replacement of bornite, blue chalcocite, and coaly material by white chalcocite with very little preservation of plant structures. Where bornite was replaced, graphic intergrowths formed.
5. Recent meteoric alteration forming covellite, malachite, and azurite.

ACKNOWLEDGMENTS.

The writer is indebted to Mr. R. W. Stone of the Pennsylvania Geologic Survey for calling attention to this new occurrence and for criticizing the manuscript, to Dr. Donald M. Fraser for helpful discussion, and to Prof. Eric Sinkinson, Fuel Technologist of Lehigh University, for the analysis. Mr. H. W. Ahrenholz accompanied the writer on a visit to the localities.

LEHIGH UNIVERSITY,
BETHLEHEM, PA.,
May 2, 1938.

A DIP-NEEDLE SURVEY OF THE TOIVOLA-CHALLENGE MINE AREA, MICHIGAN *

CARL A. LAMEY.

ABSTRACT.

A dip-needle survey of a heavily drift-covered part of the Keweenawan copper district of northern Michigan, in which there are few outcrops, was undertaken in an effort to trace the major Keweenawan units beneath the drift. Small but persistent variations in dip-needle readings made it possible to locate several belts of basic flows, and to trace a number of faults and shattered zones. From the dip-needle readings, a geologic map was prepared. Interpretation of this map indicates that a large part of the Keweenawan series is present in the area, including horizons from the Baltic, or lower, to the Great conglomerate, and that the Keweenaw fault is cutting higher into the series to the southwestward, eliminating some of the lower horizons.

INTRODUCTION.

In 1927 the Michigan Geological Survey initiated a program of geological mapping in the Michigan copper district. The glacial overburden in much of the region made it desirable to use some geophysical method in conjunction with the mapping of outcrops. It had been demonstrated that magnetic surveying by means of the dip-needle was satisfactory for tracing many of the Keweenawan lava flows of the district,[1] and this method was adopted.

Between 1927 and 1930 a survey of much of the area between Calumet and Painesdale was completed, and in 1937, mapping was advanced southward into the Toivola-Challenge mine area (Fig. 1, inset map). In this survey the writer was assisted by

* Published by permission of the Geological Survey Division, Michigan.

1 Aldrich, H. R.: Magnetic surveying on the copper-bearing rocks of Wisconsin. Econ. Geol., vol. 18, pp. 562–574, 1923; Broderick, T. M., and Hohl, C. D.: Geophysical methods applied to exploration and geologic mapping. U. S. Geol. Surv. Prof. Paper 144, pp. 156–168, 1929. The latter paper, although not published until 1929, was based, in part, on commercial work done in the Michigan copper district prior to the beginning of the magnetic survey started by the Michigan Geological Survey in 1927.

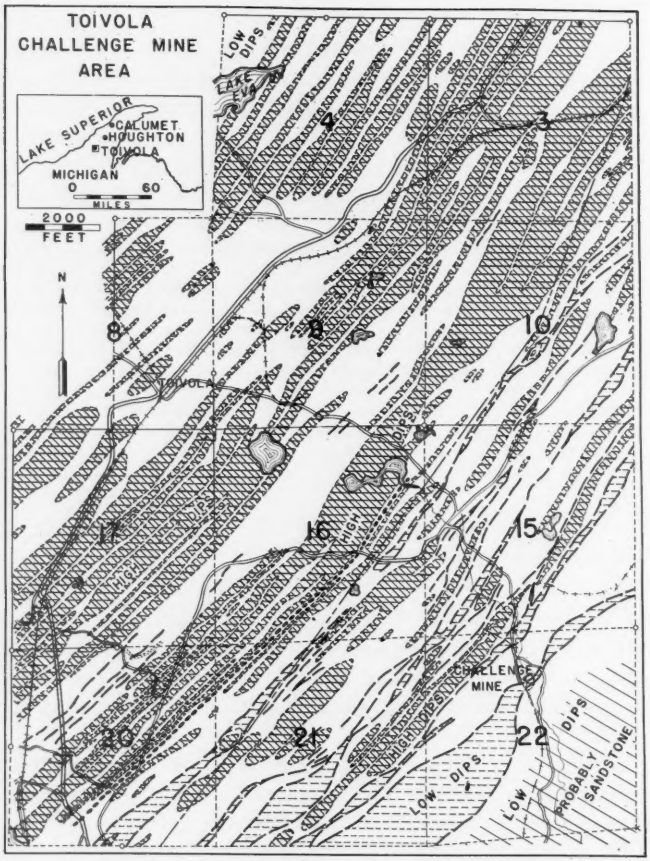

FIG. 1. Geologic map of the Toivola-Challenge mine area, Michigan. Basic flows indicated by rhomb pattern, conglomerate by elliptical, sandstone by diagonal lines, and shattered zones by broken horizontal lines. Broken, heavy lines indicate faults and fault boundaries of shattered zones; long and short dashes indicate a transmission line; circles, section corners.

K. Spiroff and A. N. MacIntosh, geologists and instrument men, and Frank Woodruff, Alan Fowler, and David Andrew, compassmen. Their assistance is gratefully acknowledged.

The field work comprised (1) establishing control lines and points, (2) making dip-needle observations, and (3) general mapping, as the only maps available were a few road maps and an early reconnaissance map by A. C. Lane and A. H. Meuche.[2] Control was established by means of solar compass and steel tape, the control net following, approximately, the section lines. In general, dip-needle observations were made at intervals of 20 paces (52.8 feet) along section lines, along a north-south line through the center of each section, and along east-west lines every quarter mile. In addition to these general traverses, more detailed work was done in some parts of the area. General mapping and dip-needle recording were done in note books, using a scale of 20 inches to the mile. Distance and direction, except along control lines, were established by pacing and dial-compass.

TOPOGRAPHY, DRAINAGE, AND VEGETATION.

The topography of the area is typical of a heavily drift-covered region. The surface is mostly rough, as moraines of the Lake Superior ice lobe cross the area somewhat diagonally,[3] forming knob and kettle topography. However, this roughness is modified in parts of the area, due to the former presence of glacial lakes.[4] Poor drainage is characteristic of the area mapped. No large streams cross it, and marshes and lakes of variable size are abundant.

The predominant covering of the area is second-growth maple in thick stands. This second-growth, fallen timber and slashing, marshes and lakes, and rough morainic topography, retarded progress and made instrumental work difficult.

[2] Lane, A. C.: The Keweenaw series of Michigan. Mich. Geol. Surv. Pub. 6 (Geol. ser. 4), plate 11, 1911.

[3] Leverett, Frank: Moraines and shore lines of the Lake Superior region. U. S. Geol. Surv. Prof. Paper 154–A, plate 1, 1929.

[4] Idem.

OUTCROPS.

Much of the bedrock is deeply covered with glacial drift, but a few outcrops occur. Drill records in the vicinity of the Challenge mine (Fig. 1) indicate glacial cover between 29 and 172 feet in thickness,[5] but near the Globe exploration, a few miles to the northeast, the overburden is 356 feet.[6] Most of the outcrops are in the central to east-central part of section 20, but one occurs in section 16 and dip-needle readings indicate that bedrock is near the surface in the southwestern part of the latter section. The location of all outcrops is shown on detailed maps of these sections.[7]

The rocks exposed comprise ophite, amygdaloidal basalt, porphyrite, pseudo-amygdaloidal melaphyre, and felsite conglomerate.[8] The ophites have augite crystals varying from 2.5 to 5.0 mm. in length, and in general are dark colored. These outcrops form small ridges and knobs and yield high dip-needle readings. The porphyrite, which crops out as a smooth, flat surface across an old road in section 16, is fine-grained. It contains an abundance of iddingsite and serpentine, but minute, lath-shaped plagioclase feldspar crystals, not badly altered, are also present. Dip-needle readings on this outcrop are about normal, that is, neither high nor low. The pseudo-amygdaloidal melaphyre may represent the bottom part of a flow. Dip-needle readings on the outcrop, in section 20, are slightly below normal but gradually increase northward to a high of about 5 degrees above normal. The rock is fine-grained and has a somewhat reddish color due to the presence of earthy hematite varying in size from minute specks to pieces about 5.0 mm. across. An outstanding characteristic observed is the presence of pseudo-amygdaloidal "knots" of chlorite alone and chlorite with calcite. Some of these "knots" have the appearance of inclusions, and in the larger ones observed (50 mm. long and 25 mm. wide) earthy hematite spots

[5] Lane, A. C.: Op. cit., vol. 2, pp. 506–515.

[6] Idem: p. 832.

[7] Available from the Michigan Geological Survey if desired. The maps show dip-needle readings, also.

[8] All rock determinations and descriptions are megascopic ones.

occur within the chloritic areas. The amygdaloidal basalt is of a somewhat scoriaceous type. The cavities are well filled, almost wholly with calcite. Dip-needle readings on the outcrop are slightly below normal. Immediately above this amygdaloidal basalt, a felsite conglomerate crops out along a small stream valley. This is a rather coarse conglomerate containing well-rounded to subangular quartz porphyry and feldspar porphyry pebbles, 15 to 75 mm. or more in diameter. Feldspar phenocrysts are the most outstanding constituent of the pebbles. These phenocrysts vary in size up to 3 mm. or more in length; in color from flesh or pinkish to pronounced red; and in composition apparently from orthoclase to acid plagioclase. The scanty matrix, which has a somewhat grayish-white color, apparently is composed chiefly of quartz and decomposition products of feldspar. On the outcrop, dip-needle readings are 3 to 4 degrees below normal, and about 2 degrees lower than readings on the underlying amygdalodial basalt.

THE CHALLENGE MINE.

The only mine in the area, the abandoned Challenge exploration in Section 22, T. 53 N., R. 35 W. (Fig. 1), was sunk to a depth of slightly more than 850 feet, and four cross-cuts made at depths of about 300 feet, 400 feet, 700 feet, and 850 feet.[9] From the eastern end of the 700-foot cross-cut two exploratory holes were drilled southeastward. In these drill holes the Eastern or Jacobsville sandstone was encountered at distances of 367 feet and 406 feet. The longest of the cross-cuts, the "third level cross-cut" at a depth of about 700 feet, was extended northwestward 1045 feet and southeastward 1409 feet from the shaft, giving a cross-section 2454 feet long. This cross-cut was described briefly by Lane.[10]

Copper was found at several horizons, apparently the most promising ones being lode E, northwest from the shaft, and lodes 10 and 11, southeast from the shaft. Lane thought that the latter two lodes might possibly represent the Baltic horizon.

[9] Lane, A. C.: Op. cit., Fig. 59, p. 834.

[10] *Op. cit.*, pp. 521–523.

Some evidence of faulting was found in the mine. A fault striking S. 52° W., dipping 87° 30′ to the south, with a displacement of about 200 feet, causing repetition of lode 2, was crossed about 200 feet northwesterly from the shaft. Drill holes indicate much brecciation easterly from the shaft at varying distances.[11]

A variety of material was observed on the mine dump, the most outstanding characteristic of much of it being marked brecciation. The rocks observed include felsite conglomerate containing porphyritic pebbles embedded in a greenish to grayish sand matrix; sandstone of at least two kinds, one very dense, fine-grained, and banded, the other much coarser and somewhat friable; ophite; breccia; amygdaloidal basalt; and vein material. Six kinds of amygdaloid were observed: (1) distinctly reddish, fairly porous, containing chiefly calcite and serpentine; (2) reddish to purplish, moderately porous, having some large amygdules containing chiefly serpentine and quartz; (3) dense, gray, containing calcite, quartz, epidote, serpentine, and small quantities of copper; (4) greenish, containing much epidote; (5) epidotized amygdaloid showing epidotization of basalt but not of amygdules, the latter containing quartz, calcite, prehnite, and some copper; (6) broken amygdaloidal top of flow, consisting of basalt fragments with sand silted down between them. Vein minerals are chiefly quartz and calcite, but include prehnite, epidote, a carbonate which is probably ankerite, and adularia, with small amounts of copper. Neither silver nor sulphides were observed. In addition to the small amounts of copper noted in the amygdaloid, some thin sheet copper was observed.

ANALYSIS OF DIP-NEEDLE OBSERVATIONS.

Dip-needle observations throughout the area may be divided into three groups: high, normal, and low. Normal dip for the area is taken as 10 degrees, but deep glacial overburden makes 8 or 9 degrees equivalent to normal in parts of the area, although, of course, the true normal reading for the area has not changed.

[11] Idem, pp. 514–521, description of drill holes 2 and 5.

However, this relative difference makes it necessary to consider various parts of the district separately for the purpose of computing highs and lows. The high and low readings may be further subdivided, the former into three groups, weak, moderate, and strong, and the latter into two groups, weak and moderate. The departure from normal in these groups is as follows: weak highs, 1 to 2 degrees above normal; moderate highs, 3 to 6 degrees above normal; strong highs, more than 6 degrees above normal; weak lows, 2 to 3 degrees below normal; moderate lows, 3 to 5 degrees below normal.

In the area there are two principal belts of highs, one subordinate high belt, and numerous short and discontinuous high belts; five more or less continuous belts of lows, and one principal and one secondary area of lows (Fig. 1). The two principal high belts extend diagonally across the central part of the area mapped and are separated from each other by a belt of normal readings in which some lows occur. The subordinate high zone crosses the southeastern part of the area, to the west of the abandoned Challenge mine. The most pronounced belt of low readings occurs southeast of this subordinate high zone. This is the most easterly low belt. Other low belts extend in general parallel to it and are confined chiefly to the eastern part of the area. The two areas of low dips are in the extreme southeast and the extreme northwest parts of the district (Fig. 1).

From the northeast to the southwest there is a tendency for all highs to weaken and to approach or become normal readings near the central part of the area, then to show more strength southwestward, and finally to weaken again near the southern end of the area.

In general the low belts are much more irregular than the high ones, and, although they follow the same general strike, they cut across the highs and split around them. Characteristically they are weaker and narrower to the west and north, and become stronger and wider toward the east and south.

For the most part, variations in dips throughout the area are small. Locally, there are variations of as much as 28 degrees

within 50 feet, but such conditions are exceptional. The part of the area in which dips show the greatest contrast is section 20.

Interpretation of Observations.

Because of the general absence of outcrops throughout the area surveyed, and the thickness of the overburden, geological interpretation is particularly difficult. Moreover, as previously indicated, many of the high belts are weak, in general but 1 or 2 degrees above normal, and strong belts are the exception. Nevertheless, readings of such a small amount above normal are believed to be significant if they are sufficiently persistent. Again, because of the character of topography and vegetation, the amount of detailed work was small. Additional detailed work would undoubtedly lead to a more accurate interpretation. It is believed, however, that the accompanying map (Fig. 1) offers a fairly reasonable interpretation of the major geologic structure of the area.

The three groups of dip-needle readings—high, normal, and low—together with the few outcrops observed, form the basis for geologic interpretation. In general the high readings are believed to indicate the presence of the more massive and ophitic parts of basic flows. The normal readings may indicate amygdaloidal parts of flows, as well as melaphyres and other types of flows, and also some sediments. Many of the low readings, especially the stronger ones in belts of irregular width that split around and cut across high belts, have been interpreted as faults, but some of the weak to moderate lows are known to indicate the presence of sediments. A brief discussion of the various interpretations follows.

Basic Flows.—The most persistent belt of basic flows, and the only one in which outcrops were observed, cuts diagonally across the central part of the area, passing through sections 3, 10, 9, 16, and 20. This belt is underlain by a felsite conglomerate which crops out in section 20. An inspection of the map of the region to the northeast of this area, previously prepared by the Michigan

Geological Survey, indicates that this belt may correspond to the one overlying the Kearsarge conglomerate.

A second belt of basic flows, represented by highs that are generally weak but show exceptional strength for a very short distance in the northwestern quarter of section 9, passes through sections 3, 9, and 17, lies to the northwest of the one just described, and is separated from it by a zone in which it is believed some faults occur. If the principal central belt represents the one above the Kearsarge conglomerate, it is possible that this northwestern belt may represent the zone above the Allouez conglomerate. The distance between the conglomerate in section 20 and the southeastern side of this second belt of basic flows is roughly comparable to the distance between the Kearsarge and Allouez conglomerates.

A third belt of basic flows, which is narrow but somewhat persistent for a short distance, passes through sections 15, 22, and 21. This is the one about 1200 feet northwest of the Challenge mine, in section 22. The dip-needle readings along this belt are not much above normal, but are moderate in part of section 22. It is possible that this belt may represent the Isle Royale horizon. The distance between the conglomerate of section 20 (if it be projected along the strike into section 16) and this zone northwest of the Challenge mine is roughly comparable to the distance between the Kearsarge conglomerate and the Isle Royale horizon.

Other basic flows throughout the area form discontinuous belts. These belts are generally represented by weak highs that pass into normal dips along the strike.

Conglomerate.—The only conglomerate exposed in the area is the felsite conglomerate in section 20, lying beneath the persistent belt of basic flows. This may represent the horizon of the Kearsarge conglomerate, as previously suggested. Dip-needle readings on the outcrop are a few degrees below normal. This horizon was projected northeastward as far as seemed practical from the recorded dip-needle readings, but its position even for that distance is doubtful, as the dips approach normal.

In the extreme northwestern part of section 4, north of Lake Eva, there is an area of low dip-needle readings. These lows

should indicate the presence of some horizon rather high in the Keweenawan series, and it is possible they may represent the beginning of the Great conglomerate.

Amygdaloid.—Beneath the conglomerate outcrop in section 20 there is exposed an amygdaloid that has been described. This is the only outcrop of amygdaloid in the area. It is not shown on the general map because of its small size, but its position is indicated on the detailed sheet for section 20. It was impractical to attempt to trace it, as dip-needle readings on the outcrop were approximately normal.

Sandstone.—An area in the southeastern part of section 22 has been interpreted as probably underlain by sandstone—the Eastern or Jacobsville sandstone, separated from the lava flows by the Keweenawan fault. This interpretation should be correct, as drill holes from the eastern end of the third-level cross-cut of the Challenge mine penetrated sandstone at distances of about 1700 to 1800 feet S. 29° E. of the shaft. Practically all dip-needle readings taken in this area are uniformly moderately low.

Faulting.—Any attempt to establish the presence of faults, without outcrops or drill records, is difficult and may lead to uncertain results. Not all low readings can be interpreted as caused by faulting, as the normal dip is lowered by excessive overburden, and subnormal readings are characteristic of certain sediments. Moreover, faulted areas of sediments or thin flows would be difficult to detect, as faulting probably would not cause sufficient deviation from the normal dips. Consequently it is recognized that some of the probable faults shown on the map may represent conglomerates or other material causing low readings, and some actual faults may not be shown. However, in those cases of very irregular low belts, especially those splitting around areas of highs, interpretation of faulting appears to be logical.

In the vicinity of the Challenge mine it is possible to verify some of the postulated faults by means of the mine and drill records. These records, which have been discussed and cited in foregoing pages, indicate faulting to the west, east, and northeast of the shaft. In general the known faulting conforms well with that indicated by dip-needle readings. Also, it appears significant

that faults previously postulated to the northeast of the area under discussion, which were established in part by outcrops, coincide well with the projections of those shown in this area.

PROSPECTING.

The most favorable places for copper concentration in this region are generally assumed to be beneath barriers in rocks of sufficient permeability and of suitable chemical character.[12] The influence of these factors has been discussed by Butler and Burbank.[13] Although favorable conditions have been produced by a variety of causes, faulting apparently has been important.

A structural map compiled almost wholly from dip-needle readings, such as the one accompanying this paper, although furnishing no information regarding chemical character of rocks, does give some information as to possible permeability insofar as that is due to pre-mineral fracturing, and some information as to the probable location of more massive flows and of zones of faulting. A map such as this, therefore, may be of assistance in prospecting.

If the central belt of basic flows, underlain by a conglomerate, represents the Kearsarge horizon, then at least four major horizons should be present in the area—the Allouez, the Calumet and Hecla, the Kearsarge, and the Isle Royale. Beneath the Isle Royale the Baltic horizon should be represented, also, possibly east of the Challenge shaft. The presence of these horizons, however, does not mean that they will be mineralized, as favorable conditions for copper deposition may have been lacking. However, if favorable structural conditions appear to be present, prospecting might be warranted.

An analysis of probable structural conditions, as shown by Fig. 1, indicates a few locations that perhaps are more favorable than others. These are discussed briefly.

(1) The area in section 22, beneath the persistent basic flow about 1500 feet west of the Challenge shaft, might deserve exploration. At this location the possible combination of a basic

[12] Butler, B. S., and Burbank, W. S.: The copper deposits of Michigan. U. S. Geol. Surv. Prof. Paper 144, pp. 115–118, 1929.

[13] Idem.

flow not badly shattered, probably underlain by a faulted zone, might prove favorable.

(2) Between the conglomerate horizon indicated in sections 20 and 21, and the zone of apparently shattered rock to the southeast, conditions might prove favorable. Dip-needle readings give very little information as to the probable character of material in that zone, but an outcrop of amygdaloid was noted beneath the conglomerate.

(3) A third possible area for prospecting may be the zone between the bottom of the basic flows and the zone of apparent faulting extending through the northwestern part of section 20, the southeastern part of section 17, the northwestern part of section 10, and the western part of section 3.

CONCLUSIONS.

Two principal belts of basic flows, and one subordinate belt, may be traced through the area mapped. These belts apparently represent, from northwest to southeast, flows above the Allouez, Kearsarge, and Isle Royale horizons.

Several zones of faulting appear to exist. These become more abundant toward the southeast, and the width of shattered zones also increases in that direction. This relation apparently is a consistent one, as the Keweenaw fault probably crosses the southeastern part of the area.

A large part of the Keweenawan series probably is present in the area, and possibly includes horizons from the Baltic, or lower, to the Great conglomerate. The probable course of the Keweenaw fault indicates that it is cutting higher into the series to the southward in this area, and eliminating some of the lower horizons.

The major structural elements of the rocks in this area are thought to be indicated on the map showing geological interpretation. It is hoped that this map may be of some value in connection with future prospecting.

OHIO STATE UNIVERSITY,
COLUMBUS, OHIO,
May 17, 1938.

EFFECT OF A SEA LEVEL CANAL ON THE GROUND-WATER LEVEL OF FLORIDA—A REPLY.

SIDNEY PAIGE.

THE discussions of my paper "Effect of a Sea-Level Canal on the Groundwater Level of Florida"[1] by J. A. Brown in this JOURNAL, (Vol. 32, pp. 589–599, 1937), and by D. G. Thompson, O. E. Meinzer, and V. T. Stringfield (this JOURNAL, Vol. 33, No. 1, 1938) raise questions that I am glad to discuss, but reflect views with which I cannot agree.

Few who may read the reply that follows could have had the time or opportunity to examine the extended report entitled Annex III, Report of Geology and Groundwater Board, Engineering Geology, Hydrology-Meteorology, Vols. I and II,[2] wherein are presented results (surveys, drilling programs, geologic, hydrologic, and meteorologic data) of five years' study directed toward the selection of a canal route across the peninsula of Florida. This report should be of interest to serious students of the canal problem, and places the concluding sentence of the discussion of Messrs. Thompson, Meinzer, and Stringfield in a somewhat odd light. They say: "We believe that such results (damages) are distinct possibilities and that *they deserve serious consideration* instead of *being swept aside* (italics mine) under the assumption that no damage will be done."

Brown's apprehensions regarding the effects of a sea-level canal revolve around two phenomena (and essentially this position is taken by my later critics); (1) changes in groundwater gradients and presumably what this might entail in damages, (2) salt water contamination. I shall not criticise either discussion on the basis that the terrain was not studied in person, as Mr. Brown suggests might come to pass. But if statements are made that are incorrect and these mistakes inhere in ex cathedra posi-

[1] ECON. GEOL., 31, pp. 537–570, 1936.

[2] Report of Special Board, U. S. Army Engineers, dated September 1, 1936.

tions, then—unsound interpretations that follow may in part at least be ascribed to such a coincidence.

Referring to comments by Mr. Brown, I wish to say that in having acknowledged " the extensive and valuable work carried on by the U. S. Geological Survey . . .," I feel that I fulfilled my obligations toward that efficient organization, and in acknowledging the authorship of the Geological Survey in the title of the maps used as illustration, I expressed my obligation. Mr. Stringfield's valuable paper which in no way discussed the Canal had not been published at the time my paper was submitted, but had been placed at our service confidentially at the inception of the work.

Respecting reference to the earlier work of Herzberg, in connection with what I have termed a " floating reservoir," I might add that I regarded the " principle " as well established, and did not presume that other geologists were unacquainted with it. The remaining papers referred to by Mr. Brown, including his own, I have never read. I appreciate Mr. Brown's courtesy in bringing them to general attention and shall look forward to reading them. Responsibility for the application of the " principle of Herzberg " to conditions in Florida, particularly with reference to the solution of the engineering problem of a canal, must fall on the shoulders of the " Special Board," of which I was a member, appointed by the District Engineer to study the water problem.

It cannot be overemphasized that the practical problem that must be faced and which has been dealt with in my paper and at greater length in official reports may be phrased thus: " What damage, if any, will arise through changes in the position of the watertable of Florida by the construction of a sea-level canal across the Peninsula of Florida along Route 13B? " I have gone to considerable lengths to point out that changes in the position of the watertable will be substantial, but that these changes will be of little consequence in terms of damage, and this broad conclusion was concurred in by an independent committee of the Department of Agriculture.

Wherein originally arose the grave apprehensions of Messrs.

Thompson, Meinzer, and Stringfield? It is enlightening to examine Stringfield's views,[3] published as late as 1933. Stringfield said, and he referred to the *recharge of water* in NW. Hillsboro County and Polk County (one should have before one a piezometric map to fully appreciate this statement): "Recharge of the groundwater of the Ocala limestone occurs chiefly where it crops out north of this area *in Sumter, Citrus, and Marion counties* (italics mine). *Recharge* of the Tampa limestone (referring to the Tampa High) occurs chiefly east and north of the area where the formation crops out in *Hillsboro, Pasco, and Hernando counties"* (italics mine). These two statements disclose a fundamental misconception regarding the functioning of the outcrop area of Ocala limestone, with respect to "intake" *vs.* "discharge." Stringfield erroneously regarded that area as the great recharge area, whereas as a matter of fact it is the great discharge area and recognition of the fact played an important part in the selection of this canal route, as opposed to many others, by the Army Engineers.

The Tampa "High" is built up by recharge from rainfall on its surface and by no other means. It is a mound on the northwestern slope of the great southern water table high. Some water moves northward from it toward the canal line. *None moves southward to it from the canal line.* On page 19 et seq., Mr. Stringfield says again, in discussing recharge at Orlando: "In August, 1930, the water in the wells in Orlando rose to levels 6–7 feet higher than in August, 1931, and there was a hydraulic gradient in *all directions* (italics mine) from a central point in the city . . . due to the heavy rainfall of that summer. During the wet season the water level rose to such heights that some of the wells flowed under artesian head instead of taking in water from the surface." Confronted squarely by this phenomenon, Mr. Stringfield continues: "Natural recharge of the Ocala limestone occurs where the formation crops out *northwest of Orlando in Sumter and Marion counties"* (italics mine). Again this fundamental and inexplicable misconception of the movement of water in Florida; this inclination to have it run uphill.

[3] Florida State Geological Survey, Bull. 11, page 15, 1933.

These passages lead me naturally to a question raised by Messrs. Thompson, Meinzer, and Stringfield on page 93. Referring to my estimate of 44 per cent as the probable area of "intake" in Florida, the question is raised, "How was it computed?" I am glad to reply. It was computed after a physiographic study of the surface of the peninsula, directed toward distinguishing areas of sink-hole terrain from areas characterized by normal dentritic drainage and by correlating these distinctive areas with the position and nature of the underlying reservoir, using Stringfield's map as a base. Following this field study, a planimeter was used on a map in the office with the results recorded.

It is indisputable that sink holes denote areas of intake. According to Messrs. Thompson, Meinzer, and Stringfield, however, the area to which I referred as open reservoir merely represents the part of the peninsula in which flowing wells cannot be obtained, but does not show, they affirm, that all of the non-flowing area is intake area. I regret to disagree. In Florida all sink-hole area is intake area whether the water descends to a water table in Ocala limestone, or whether it descends to a pressure level in the stratigraphic column above it. All such descending water ultimately joins the reservoir to build up head. *There is no other mechanism to account for the piezometric highs north and south of the canal.*

Thompson, Meinzer, and Stringfield object to the concept underlying my use of the term "open" and "closed reservoir. They suggest these terms connote two reservoirs, although I have explicitly stated that we are dealing with only one important reservoir. Evidently my meaning was not clear. I regard the concept as very useful because it serves to distinguish areas of intake from areas where intake is not normally possible. I describe the "open" reservoir as "that portion of the Floridian plateau wherein water in cased wells either penetrating the Ocala limestone or the Hawthorn above it will not rise above the ground surface." All such area constitutes potential intake area *whether a water table or a pressure level exists below the surface.* Mr. Stringfield's very valuable map is a piezometric map (entitled so,

and correctly) although it contains in places *water table* contours. My " open " reservoir lies in part beneath areas where piezometric contours are located beneath the surface. My " closed " reservoir embraces areas of artesian flow at the surface and none of it normally includes surface " intake " area. Where is the " no man's land " referred to by Thompson, Meinzer, and Stringfield? They say: " Each hill where wells do not flow would be underlain by an 'open' reservoir and would be separated from numerous neighboring 'open reservoirs' by the 'closed reservoirs.'" This interpretation, it seems to me, misses the point. Where this condition exists there are numerous *intakes* to the main reservoir. The concept has to do with intake.

Data are also introduced to support the thesis that two important water tables occur in Florida. All workers in Florida are aware that some lakes are perched and that southern Florida may have two water tables. Thompson, Meinzer, and Stringfield say: " Wells tapping the Ocala on the south and west shores of Lake Apopka have a head several feet above the lake but north of the lake the artesian head is several feet below the level of the lake." To me this fact (of which we were aware since our circuit of observation wells extended this far south) has always been important and is interpreted to prove that Lake Apopka is a water table lake lying on the northern slope of the great southern piezometric high, one of the wettest regions of the United States. Under such conditions my critics would not expect the lake to have a sloping surface.

Lake Weir, some eleven miles from the canal line, appears at present to be perched. We are content that this is so, although if it were not and the cutting of a canal resulted in a lowering of its surface, such *damage* as might be expected would inhere in a widening of its sandy strand with an added area for sun-bathers.

Messrs. Thompson, Meinzer, and Stringfield present six pages of data to prove that the Ocala limestone is permeable in depth; taking exception to my position that permeability decreases in depth. They bring coals to Newcastle. They point to progressive increasing flow with depth in the Jacksonville artesian field

implying that the increase is due to increasing permeability of the limestone; but overlook and do not discuss the fact that in this field increasing artesian heads appear with increasing depths, which alone would increase flow. We are inclined to connect these increasing heads with the flow-mechanism of the floating fresh-water reservoir, a subject which deserves further study, but cannot be pursued here.

In my opinion Ocala limestone and the Eocene limestone beneath this unit, together do become progressively less permeable in depth, and I conceive only sluggish circulation of fresh water at great depths. It is a matter of observation in all quarries that the upper portion of the Ocala limestone is exceedingly permeable (indeed reveal phenomena worth traveling to Florida to see), and becomes progressively less so in depth. This conception colors my ideas respecting the probable operation of the reservoir after a canal shall have been excavated.

In a recent book entitled "Groundwater" by C. F. Tolman, the following statement is made on page 543, referring to the fresh-water floating reservoir of Hawaii. "The curvature of the water table varies inversely with the permeability of the water-bearing material and, as the lavas are *extremely permeable* (italics mine) the water table is nearly flat and the depth of fresh water below sea level is small. (A matter of a few feet.)" What are the implications of this principle applied to Florida, where heads above sea level as high as 130 feet prevail and where the fresh water descends to *thousands* of feet, and where progressively increasing heads are found in depths in the Jacksonville artesian field? Do these facts connote that Ocala limestone and the underlying Eocene strata are as permeable in depth as we know the Ocala to be at the surface?

Since both Mr. Brown and Messrs. Thompson, Meinzer, and Stringfield criticize my use of certain existing piezometric gradients as a basis for estimating the configuration of the piezometric surface after a canal is completed, I welcome an opportunity to develop this matter further. I believe my critics feel that I have selected the particular gradients that meet my needs, to sup-

port a pre-conceived position as to the determinants of the flow of water in Florida. Such a procedure on my part was far from the case. Rather early in my studies, I became convinced that permeability experiments on a small scale would be inadequate. Later, more data were accumulated that supported this conviction. We noted, while undertaking de-watering operations of bridge foundations under hydraulic head, that Ocala limestone devoid of solution channels displayed impressive resistance to flow of water. We were convinced that an appraisal of the average permeability of large volumes of Ocala limestone was not possible on the basis of permeability tests of small specimens of the rock. Some thought was given to, and estimates made of the cost of pumping tests on a grand scale, but the cessation of work interrupted both planning and execution. There remained the possibility of an appraisal based on the principle that the piezometric contours, their average position (fluctuation with rainfall and drought, relation to influent and effluent drainage, relation to physiographic or geologic features), represented the integrated resultant of all determinants and that, if an analysis could be made in terms of all these factors of the effects to be expected from a canal cut, then the conclusion would be on the soundest basis obtainable. It was necessary, therefore, to examine all gradients that might throw light on our objective. And we were confronted fortunately with at least two practical experiments conducted on a grand scale which illuminated the subject. I refer to the two dams, to one constructed on Oklawaha River with abutments in the "Upper series," but particularly to the other on Withlacoochee River with foundations and abutments entirely within Ocala limestone. Both served to raise the water table permanently, in the latter case about 28 feet.

Mr. Brown says: "As a matter of fact, it is questionable whether all or possibly any of the gradients pictured can be said truly to represent gradients normal to the area of surface exposure of the Ocala limestone." This is a misstatement. Gradient C is entirely within an area of Ocala limestone; Gradient G is entirely within an area of Ocala limestone; Gradient F is entirely

within an area of Ocala limestone, and the statement will mislead because nowhere have I implied that other gradients pictured were all in Ocala limestone. That was not the purpose of their exposition. Mr. Brown may take the position that, although these gradients are within areas of Ocala outcrop, they are not normal. What is normal? A water-table gradient in rock (the slope of the water table) is the resultant of the permeability of the rock, and the quantity of water supplied to induce movement through it. Where it is supplied, along the gradient, also makes a difference. My purpose in illustrating these gradients was very definite. Gradient G is where a narrow dam constructed on Ocala limestone has raised the water-table level 28 feet, that is, the resistance to flow of water through Ocala limestone at this point (under the conditions that prevail today of rainfall and surface flow in Withlacoochee River) is sufficient to set up this gradient in the short distance between the spillway crest and the toe of the dam. Mr. Brown suggests, and also Messrs. Thompson, Meinzer, and Stringfield, that the Alachua formation which in places overlies the Ocala limestone is responsible for this resistance to flow. This suggestion is not supported by facts. Numerous drill holes in this vicinity have proved conclusively, not only that the Ocala limestone is the only *rock* present, overlain by sand and silt at and beneath the surface at the dam, but that *more cavities are here present than have been observed at any other place along the canal line.* These being the facts of record (the drill cores and logs may be examined), the importance of Gradient G is apparent; for engineering plans include a dam across Withlacoochee River and across Blue Springs River to regulate the flow of these streams to the canal and such dams properly constructed will maintain a pool at spillway level and stabilize the position of the water table upstream from the dams.

It is a matter of record that the bottom of Withlacoochee river, 800 feet west of Dunellon, is but six feet above sea level. Blue Springs Run joins Withlacoochee River at Dunellon. Therefore, before the Florida Power Corporation dam was built, Blue Springs Run was discharging into a river the bottom of which

was near sea level. Blue Springs Run entered Withlacoochee River at approximately 19 feet elevation above mean sea level.

The springs at this time (before the dam was built) flowed copiously as they do today. It is not conceivable, in my opinion, that a reduction of the water surface of these rivers to sea level can destroy all flow of the springs. (Mr. Brown suggests that they may dry up.) When it is recalled that a dam will be constructed across Blue Springs Run with a deep grout curtain, it is reasonable to suppose that Blue Springs will be quite stable enough to support a pool behind the dams after all flow losses around and beneath the dam have been accounted for.

My discussion of gradients involves other considerations than that of their application to the dams. The flow of water through rocks (quantity per unit areas) is a function of several factors, head (or difference of potential), permeability, quantity of water supplied and where it is supplied, and length of gradient. The gradient is a slope or curve of equilibrium, a balance of these factors. There is nothing freakish (as suggested by Mr. Brown) about Gradients D, F, and G. To overlook the import of Gradient G, for example, is to deliberately discard factual evidence bearing directly on the problem at issue, as I have shown above. Gradient A is equally important. This gradient from the canal to the southern "high" is 78 miles in length. The canal will reduce the level of the water table at the canal about 40 feet to approximate sea level. The gradient (over the length of which there falls annually about 52 inches of rain) is not the locus of concentrated underground flow (see below), but lies on the central water-table ridge of the peninsula. If on a profile drawn to scale the lowering of the water table at the canal be represented by one foot, *the length of the profile would be about two miles.* The region through which the gradient passes, a great lake region, is one of the wettest in Florida or the United States. Moreover, a dam will be constructed across Oklawaha River. In my opinion, such effects as are brought about in the water table south of the canal will be *confined largely* to the *area between Oklawaha River and Withlacoochee River and will diminish southward.* The dam

across Oklawaha River will maintain a pool at spillway level (approximately the same as at present) and the slope of the piezometric surface upstream from this pool (to the south) will rise southward from this dam. Only between the two rivers will the maximum effects of the draw-down induced by the canal be felt. The southern "high" in my opinion will be unaffected.

Gradient C, as has been pointed out, is entirely within an area of Ocala limestone. It is a gradient from tide level on Suwannee River to the summit of a groundwater ridge. If Suwannee River be regarded as a tide-water canal, the gradient represents the slope of the water table from such a canal level to the summit of a water-table ridge. Thompson, Meinzer, and Stringfield say this region is unusually impermeable! Why? They refer to prevailing swamps to support their argument! The same argument would apply to all the swampy area of Lake Tsala Apopka and the lower Withlacoochee River, near the canal.

One may be impressed with, and call attention to the widely spaced piezometric contours on the opposite side of Suwannee River and the question may be raised, "Why are *these* widely spaced contours not representative of what will occur in terms of groundwater gradients along a sea-level canal?" (Such is evidently Mr. Brown's position and that of Messrs. Thompson, Meinzer, and Stringfield.) To such a question, I would reply:

The drainage basin of Suwannee River with its surface and sub-surface flow is an ancient feature. Surface and sub-surface flow lines have developed slowly in geologic time and are today represented by definite surface and sub-surface (subterranean) drainage patterns, the limiting base level of which is sea level. Where drainage is concentrated in valleys of the water table, piezometric contours are widely spaced; where drainage is not so concentrated, contours are more closely spaced. Such a group of contours is represented by Gradient C. When and if a canal is cut through Ocala limestone along Route 13B, sub-surface flow will be induced toward the canal within a mass of limestone of average permeability, but a mass wherein *ancient subterranean drainage patterns of concentrated flow do not exist,* as evidenced

by the lack of surface streams and by the lack of any such subterranean drainage patterns on the piezometric map, and the canal cut will be an artificial canyon. That water will move through the limestone, there is no doubt; but that it will move at a rate comparable to its velocity within the well-developed drainage channels of the Suwannee River system is in my opinion out of the question. Gradient C, moreover, falls from a groundwater ridge open on two sides, which drains westward to the Gulf and eastward to the Suwannee River. It is to be expected therefore that gradients falling to the canal and discharging only on one side might be steeper than Gradient C. To make my meaning clear, I refer to the analogy of "hanging valleys" in surface streams. The same relationship is recognized in underground flow through limestone in many parts of the world. It is reasonable to invoke the principle in predicting flow through Ocala limestone toward the canal. A long period of time must elapse to reduce flow through rocks to a drainage pattern maturely adjusted to a sea-level base and just insofar as this process has not operated in the past one is justified in expecting steeper gradients than prevail where the process has operated during long periods of time.

Pursuing this discussion of groundwater movement a little further, at the risk of overtaxing the interest of my readers but on the assumption that Mr. Brown and Mr. Meinzer have not understood and, therefore, that others may have misunderstood my position, I will expand briefly my conception of the nature of the flow from Silver and Blue Springs, and what one may reasonably expect to occur when a canal is excavated and controlling works are installed.

The Florida Canal is laid out to cross the Peninsula on an important topographic surface and subsurface drainage saddle. The St. Johns River, Oklawaha River, and Withlacoochee River flow north many miles toward this saddle. The two latter rivers turn abruptly east and west, one toward the Atlantic Ocean, the other to the Gulf of Mexico. Oklawaha River rises in a chain of important inter-connected lakes, constituting a part of the wettest terrane of Florida, and drains north to enter St. Johns River

about tide level, whence its waters mingling with the St. Johns River flow to the ocean. Withlacoochee River rises on the southern border of the most prominent topographic high of Florida, and flows northward through lakes and swamps *so widespread that for years schemes have been formulated, but never practiced on a large scale, to drain the terrane or part of it in order that submerged lands might be put to agricultural use.* This stream turns westward at the canal line to enter nearby the Gulf of Mexico. Between these rivers lies the wettest region of Central Florida, the water from which (that portion which is not evaporated or otherwise dissipated) enters the ground to drain northward, eastward, and westward to these streams or to the Gulf of Mexico on the west or the St. Johns River on the east.

North of the canal, there rises a comparable topographic highland, a portion of which lies north of Ocala with elevations about 150 feet; another portion lies in Putnam and Clay Counties with equivalent or higher elevations. Whither flows the surface water from this highland? An important part reaches the Gulf of Mexico via Santa Fe River and Suwannee River; a part drains eastward through Orange Creek from the lakes to St. Johns River, but of the entire remaining terrane, embraced by the course of Santa Fe River and Suwannee River (on the north and west), and the saddle through which the canal line passes (on the south), *there is not a single important surface stream draining toward the canal, except Blue Springs and Silver Springs Runs.* The water falling on this terrane passes downward to join the underground reservoir, and significantly enough, Silver Springs discharges on the average about 800 cubic feet per second and Blue Springs about 600 cubic feet per second. Between Orange Springs Run and the Gulf of Mexico there is no other important outlet for precipitation. The inference, if not obvious, is very pointed; Silver Springs and Blue Springs are the outlets of submerged flow systems draining from the north. There is surface evidence besides these broad relationships to support this view. Thirty-five hundred feet east of Silver Springs, a surface tributary flowing water only in rainy seasons, enters Silver Springs Run. This

tributary drains the swamps and lowlands to the north. For two miles north, the tributary is confined to a narrow trench indicating that surface erosion played the dominant part in its formation. That this stream has lost the greater part of its surface flow to underground drainage, and that some of this water is diverted underground to Silver Springs is a very reasonable assumption.

Silver Springs Run meanders southeastward for about five miles entrenched in a well-developed flood plain, to its junction with the Oklawaha River. This normal stream valley of Silver Springs Run with its tributary drainage, points to a drainage system rising to the northwest and north, a system which has been operating a long time. It may be pointed out here that Silver Springs arises near the edge of the overlapping "Upper Series" beneath which to the east, not far distant, artesian conditions prevail. No doubt the drainage system supplying Silver Springs was initiated in the past when the upper series covered all this terrane. By the removal of this cover, the system was exposed at this point and the flow from it has subsequently incised the normal surface drainage pattern that prevails below the springs.

Blue Springs is an even more striking example of discharge from a submerged drainage system. Below the springs the stream meanders in a generally southerly direction for approximately six miles to its junction with Withlacoochee River. The topographic depression that marks this surface drainage is continued northward a short distance east of the springs. *There has never been any doubt in the minds of those who have studied the flow of Blue Springs that the water comes from a terrane north of the Canal line.*

Independent hydraulic engineers and, I believe, members of the U. S. Geological Survey, have estimated that there is sufficient area within the groundwater flow areas tributary to Silver Springs and Blue Springs, north of the canal, to supply the water that flows from the springs under present average annual rainfall.

A succession of drill holes driven to fifty feet, more or less, below sea level partly encompassing Silver Springs on the west, south, and east did not reveal any cavities of appropriate size to

deliver the present flow to the springs. Instead, an irregular surface of Ocala limestone was discovered, overlain by sand and silt and, where cavities once existed, these were found to be filled with sand and silt.

Silver Springs pool and Silver Springs Run undoubtedly receive some water from the bordering water table, which stands slightly above pool level, and complete drilling undoubtedly would show the springs standing in a shallow depression cone of the water table, breached where the stream flows out, but the 800 second feet flowing from the springs does not derive from these low heads but is supplied, in my opinion, by high heads lying to the north and transmitted through passages of such capacity that the head is not destroyed by frictional resistance to flow. I cite this latter investigation in partial reply to a statement by Messrs. Thompson, Meinzer, and Stringfield, on page 92 that, "No specific data are cited in the paper by Paige to prove that the high permeability of the Ocala limestone is confined to a shallow zone and his conclusions that neither Silver Springs nor Blue Springs will be injured . . . ." This information while not in my short paper was available to Messrs. Thompson, Meinzer, and Stringfield in official reports.

The plan proposed by the Corps of Engineers includes four dams to control the flow of water into the canal from Blue Springs, Silver Springs, Oklawaha River, and Withlacoochee River. These will have deep cut-offs. What will be the effect of those dams on the elevation of the water table? The effect of the Florida Power Corporation dam has been discussed. If the water table can be raised and held approximately 28 feet above water table at the toe of a narrow embankment placed on Ocala limestone *where it is known to be unusually permeable,* it is reasonable to suppose that modern dams with appropriate cutoff aprons can be constructed across Blue Springs Run, Withlacoochee River, Silver Springs Run, and Oklawaha River, which will maintain pool level behind these dams, *after all losses through the dams are accounted for.*

Compare the situation at Silver Springs with the Florida Power

Company's dam! The dam at Silver Springs, with a grout-curtain, will set up a head of approximately 40 feet between the pool and the canal, but the distance to the canal by the shortest line will be nearly three miles. Water falling to canal level will be forced to travel this distance through sand and silt and Ocala limestone for the terrane is essentially flat. In my opinion, the delivery of 800 second feet of water at Silver Springs pool in essentially open conduits cannot be transferred through three miles of sand and silt and Ocala limestone to the canal, at any such *rate as to dissipate the pool* at Silver Springs behind the dam. The present water table will be preserved (with a height of 40 feet at the pool), with an embayment in the water table to the east and west. *While the flow over the spillway at the dam may be and probably will be less than now flows on the average down Silver Springs Run,* there will be, in my opinion, ample water delivered at the springs to maintain the pool.

Thus I differ with my critics regarding the effect to be expected at Silver Springs. They discuss the Springs as if they were dealing with a stagnant water table—not with a copious discharge of some 20,000,000 gallons per hour, an amount which at 100 gallons per person per day would supply a city of nearly 5,000,000 population. Their conception of what occurs at the Inglis dam is different from mine. They say: "At Inglish a dam across an open channel forces the water to find a route through the surrounding rocks; in contrast, the canal (at Silver Springs) would provide the ground water with routes of escape through a long stretch at a lower level." I would say: The Inglis dam proves that the permeability of the Ocala limestone is such that the flow of water from Withlocoochee River *builds up a head of 28 feet* behind the *narrow* dam based on, and with abutments in Ocala limestone. And at Silver Springs, I would say that the dam, with a deep grout curtain and with a three-mile dam of rock between the Springs and the canal and with 800 second feet flow for the Springs will build up a head of 40 feet, which will be maintained behind the dam after all losses through it or beneath it have been accounted for. Just what "hydrologic principles"

as interpreted in the light of geologic knowledge of this part of Florida are transcended by my viewpoint I fail to see. There is no reason for not facing squarely the facts at the Inglis dam.

I do not wish to appear ungracious in replying to Mr. Brown's discussion of contamination. On the other hand, I cannot overlook lapses into what appear to me to be obviously unstudied statements, which by their implication, and far from supporting any constructive argument, lead only to false impressions. Specifically Mr. Brown says: "The Interim report of the Special Board of Engineers ascribes salinity in the Lake George area to bottom-water salting, that is to admixture of salt water from the prevailing basement of sea water, and *minimized it as unimportant"* (italics mine), and to support this statement goes on to quote from the report—" salt water encroachment from the bottom of the groundwater reservoir upward to the St. Johns River in the Lake George region is not now greater than one per cent of the total flow of the river." He then proceeds: " This statement is true enough when the small volume of naturally escaping salt water is diluted with a large volume of surface flow, *but by no means true of wells or springs."*

Mr. Brown must be aware if he has read the final report of the Board, and he has certainly been informed by me of the facts recently by letter, that by no stretch of the imagination can these statements from the Interim report be interpreted as he implies. The reference to one per cent contamination refers solely to contamination of *St. Johns River water. Never has the contamination* of wells in the Lake George depression cone been minimized. Thousands of dollars were spent in drilling in the Lake George region to specifically study this problem, to determine artesian head, to determine salinity, to estimate the ratio of intake to runoff, to estimate the ratio of salting from the ocean by way of the river to that of salt springs. St. Johns River was carefully gauged and water sampled during this study. The fact that the wells in this region are already contaminated, the presence of numerous salt springs, and the determination of low artesian heads near the lake area, all force the conclusion that the canal

cannot injure a region in which the water is already salted, nor the effects of the canal be transmitted through the existing low heads to Sanford, fifty miles distant.

Mr. Brown in a footnote has suggested that differential tilting of the Florida Peninsula may have influenced the distribution of contaminated water. Studies of terraces along the Atlantic coast and along the coasts of Florida do not support this suggestion. Rather, evidence points to remarkable stability of the coast in Quaternary time, with emphasis on changes of sea level brought about by changes in the mass of polar ice caps. It seems more probable that Stringfield's suggestion that connate water has never been flushed from the deeper strata of the southern Peninsula meets the situation. The idea of the migration of contaminated water to the northwest and northeast because outlets to the sea at the base of the "Upper Series" lie at progressively greater depths off shore has been developed by Mr. Malcolm Pirnie, but the subject cannot be discussed further at this time.

Admittedly, cutting the canal may somewhat lower artesian heads in the Lake George region (Messrs. Thompson, Meinzer, and Stringfield also raise this question). *These heads are already reduced to but four feet and the water is already salted.* The fringe of unusable water between the lake and the canal may be widened. But the population of this region is not today, and will not be in the future, dependent on salted wells.

Nor have I minimized the importance of the rise of bottom salt water with declining fresh waterheads on land. My entire paper is devoted to pointing out that such a rise is to be expected. But the importance of this change in terms of damage is, in my opinion, overemphasized by Mr. Brown and Messrs. Thompson, Meinzer, and Stringfield. The canal, frankly faced, is nothing more than an extension of the existing coast line of the Gulf of Mexico. Fresh water is present today in wells along the Gulf Coast and along the banks of Suwannee River near the coast. The depth of the fresh-water column is determined in general by the head above sea level. Similar conditions will prevail along the canal-cut in Ocala limestone, with this difference,

that except for a minor invasion by salt water near its terminal, the canal will be fresh water. Water will continue to flow off the land toward the oceans as it does today; never from the oceans toward the land until rain ceases to fall.

Just a word concerning the prospects for water at the City of Ocala after a canal is completed. I am aware that a salt-water wedge will ultimately rise beneath the canal to a height governed by the head of fresh water in the canal, and that the volume of fresh water beneath the City of Ocala will be diminished. This matter has been freely discussed with responsible officials in Florida. But if Ocala should need more fresh water than would remain directly beneath it, if heads, let us say, were reduced to 10 or 15 feet (with 400 feet $\pm$ of fresh water beneath sea level), then the City could draw on a practically unlimited underground supply a few miles to the north. These considerations point to the lack of wisdom in the use of such words as "damage" and "injury" when undefined. Human affairs are not governed entirely by permeability tests on Ocala limestone. The City of Ocala foresees benefits from a canal that will outweigh the cost of a 15-mile pipe line to the north even if this should prove desirable.

As for Sanford, fifty miles from the canal, I have no doubt that wells there will continue to be over-pumped and that contamination from salt water will increase and that if a canal were built the canal would be blamed for this condition, overlooking its prior existence.

This discussion is already overlong. Decisions affecting engineering operations cannot be decided by ex-cathedra discussions in open forums, but must be decided by those responsible.

If and when the Florida Canal is constructed, it is my opinion that the anticipated economic advantage will far outweigh the negligible damage that is to be expected from the lowering of the water table along the canal. Indeed, of the six conclusions reached by Mr. Brown, only a part of No. 4, to wit, that there will be substantial decreases in flow, conceivably even total disappearance of Blue Springs Run, Silver Springs Run, and Withla-

coochee River below Tsala Apopka Lake, is in appreciable disagreement with conclusions reached in my paper. I expect the Tsala Apopka swamp region to be somewhat drained. I consider that this would be a benefit.

Messrs. Thompson, Meinzer, and Stringfield remain "apprehensive" that Sanford may be injured.

NEW YORK CITY,
May 3, 1938.

DISCUSSION AND COMMUNICATIONS

GEOLOGY IN MODERN LIFE.

Sir: From time to time the pages of your journal give space to the despairing cries of those who see economic geology and the mother science sinking into desuetude. Certainly a problem for geologists to consider is how an understanding of the facts and uses of geology may be furthered among people in related fields of science or business.

A valuable practical example comes from Paris. There since 1932 a series of lectures has been given under the direction of the Bureau d'Etudes Geologiques et Minieres Coloniales of which Mr. F. Blondel, well known to American geologists, is the director. The lectures are a phase of the work of the School for Geology and Mineral Exploration of Overseas France.

The program for 1937–38 is typical. It began with a series of lectures by Mr. Blondel dealing with copper deposits—their general nature, distinctive features and geographic distribution. This was followed by a series of lectures and conferences on regional economic geology, the region being one of the French colonies and the lectures being divided, as hitherto, between Mr. Blondel and a distinguished visiting geologist. In the present year the topic was Indo-China, and the visitor Mr. J. Fromaget, well known for his studies in that region.

Entrance is free. The meetings are held at weekly intervals and in the late afternoon. They are attended by men of highly varied professions, financiers, business men, those engaged in colonial trade, and technical men, as well as professors and students (for whom, however, they are not expressly intended). The audiences average 150. The lectures serve to tell French citizens about their resources and to encourage colonial development by business and professional men. Incidentally (though

this was certainly not their original object) they contribute materially to the awareness of the important role—theoretical and practical—played by geology, and especially economic geology, in the modern world.

An effort of this sort, among others, may well be recommended to our complaining American geologists. Of course, one essential prerequisite is that we should overcome our academic reluctance toward speaking to the public in a language that it can understand!

CHARLES H. BEHRE, JR.

CAGLIARI, SARDINIA,
March 27, 1938.

KALGOORLIE GEOLOGY RE-INTERPRETED

Sir: In the January-February issue of this JOURNAL Dr. Frank Stillwell discussed a recent paper on Kalgoorlie[1] by Dr. Miller and me. Several points that he raised deserve further comment.

Porphyry-Slate Mass at the South End.—There is practically no generalization in the map where it shows the slate-porphyrite contacts at the south end except insofar as contacts have been projected across areas covered by mine dumps or otherwise obscured. The mapping was done in considerable detail using an aerial mosiac on a scale of 1 inch = 400 feet. We also had the benefit of a diamond drill hole put down under the Great Boulder dump. The hole supported the belief that the folded slate-Younger Greenstone contact pitches south in rough conformity with the pitch of dragfolds in the slate and of larger folds in the Younger Greenstone-Older Greenstone contact.

The map is, of course, very generalized in its picturization of the "Boulder Dyke." The numerous slate bands (mentioned in the text, p. 293) could not be shown in the small scale diagram.

Younger Greenstone, a Sill or Laccolith.—We do not regard the Younger Greenstone as a lava flow because, (1) it possesses no flow textures, and (2) its lower contact shows minor local evidences of transgression. That it is a sill or laccolith is indicated

[1] ECON. GEOL., vol. 32, pp. 285–317, 1937.

by the evidence set forth on pages 296–297 of the text. Considering the rather "revolutionary" nature of our thesis that this formation is a sill or laccolith folded with the older rocks, it is very gratifying that so eminent a geologist as Dr. Stillwell, and one who is intimately familiar with Kalgoorlie, rests his entire case against our hypothesis upon one exposure that he has never seen.

During my own observations in the Imperial Mine, I was impressed, as elsewhere, with the general conformity of the Younger Greenstone and overlying slates. I did see one exposure, possibly that reported by Mr. Finucane, where the Younger Greenstone for a few feet at least truncates the slates. This, and similar places in Australia East and Brown Hill, led us to say (p. 296) "There are, to be sure, detailed instances where the Younger Greenstone apparently cuts across structures in the older rock." There appears, however, to be a very wide discrepency in our interpretation of such evidence.

In the first place, these discordances of structure *may* be due to the intrusive nature of the contact. Figure 9A was drawn to show clearly that some transgression of beds of the Younger Greenstone has occurred—but before folding, not after. If mathematical conformity, as opposed to general conformity with minor transgressions, is the requisite of a sill or laccolith, no such intrusive body exists.

In the second place, when strong competent rocks are tightly folded with weak incompetent rocks, discordances of structure inevitably happen. I have found similar "transgressions" while mapping strong quartzites and slates that have been tightly folded. Moreover, the "shears" developed in the plastic beds, which are responsible for these transgressions, do not necessarily look like faults.

The fact that the lower contact of the Younger Greenstone formation occupies approximately the same stratigraphic horizon (for a mapped distance of nearly 15 miles), even where that stratigraphic horizon is involved in complex folds, is to the authors a far more significant fact than the local transgression

noted by Mr. Finucane. It is a fact, nevertheless, which has not entered Dr. Stillwell's discussion.

Faulting of the "Boulder Dyke" by the Main Lode Shears.— As regards faulting of the "Boulder Dyke" by main lode shears, Dr. Stillwell states, "The text is not clear as to whether such faulting is a fact or only a suggestion." The text (p. 306) reads, "Main lode shears may even fault the "Boulder Dyke" as suggested in Fig. 11." We favor this interpretation as being more plausible than Dr. Stillwell's suggestion that the "tongues" were intruded along the main lode shears. It was by no means intended as a factual denial of his theory.

The idea that the main lode shears in the Western Lode System faulted the caunter lodes was indeed proposed by Maclaren long ago, as Dr. Stillwell points out. (We say p. 308, "Maclaren early recognized the fundamental shear pattern in the Younger Greenstone which governs the distribution of lodes (and dykes) within the systems.")

Dr. Stillwell continues, "It led to a programme of fruitless diamond drilling from the bottom level of the Ivanhoe Mine in search of the Ivanhoe East lode after its supposed emergence in depth on the eastern side of the Boulder Dyke. If the Boulder Lode and the Ivanhoe East lode occupy fault planes, one would expect that in view of the acute angle between these lodes and the Boulder Dyke, any possible movement would be dissipated along the numerous slate bars that would be encountered in crossing the Boulder Dyke."

The evidence is as follows. The caunter lode shears appear to have been offset (prior to mineralization) by faulting on the main lode shears as any three-dimensional study of the western lode pattern clearly shows. This offset is in the same direction and of the same order of magnitude as the "offsets" in the dike postulated by Dr. Miller and me.

The lodes have in several instances been followed by drives well into the body of the porphyry. Since, however, the lodes become too low grade to mine where they are enclosed by two porphyry walls, they have not been followed to the limit of their extent.

That the lode shears emerge on the western side of the dike, as sugested diagrammatically in Fig. 11 of our paper, is neither proved nor disproved, the Ivanhoe drilling results notwithstanding. Kalgoorlie lodes are lenses of limited extent; many drill holes in the district have been put through unmineralized lode shears. Even the shears do not continue indefinitely.

That the lode shears may be deflected after entering the dike and continue along beds of slate as Dr. Stillwell suggests is, however, a definite possibility. I have no objection to the faults being thus lubricated with graphite.

If we accept Dr. Stillwell's argument that the "branching tongues" penetrate along the main lode shears it must be assumed first, that the shears were there before the dike was injected, and second, that there have been later post-dike movements on the shears, since the shears penetrate the dike. Both assumptions are perfectly logical. But since post-dike movement on the shears is a requirement of any theory, and since faulting of the caunter lode shears by the main lode shears is a plausible, if not inescapable, conclusion, similar faulting of the dike cannot be dismissed as an improbability.

Bending of the "Boulder Dyke."—Dr. Stillwell explains the curve in the "Boulder Dyke" by assuming that it occupies one shear direction at its southern end and another shear direction at its northern end. But the porphyry content of the "Boulder Dyke" merely follows the curved beds of slate. Does Dr. Stillwell in spite of his own strong arguments in favor of a sedimentary origin for these states (16, p. 49), and in spite of additional proofs that we have advanced (pp. 293–294), now believe, after all, that these banded graphitic slates are merely fault gouge? The curve in the "Boulder Dyke" reflects a bend in the axial plane of the Kalgoorlie syncline as we have suggested, only if we are correct in our interpretation of the Younger Greenstone as a sill or laccolith, a matter already thoroughly aired.

Slates as an Impervious Cover.—We suggested as an interesting possibility (obviously incapable of either proof or disproof) that the slates over the present erosion surface might have pro-

vided an impermeable capping to ascending ore solutions, because the slates were relatively plastic and less amenable to the development of permeable shears than was the quartz dolerite. Dr. Stillwell argues that this idea "is not consistent with the fact that exploration at the south end, near the upper slate contact, has not disclosed any appreciably large deposits of high-grade ore, whereas numerous instances of high-grade ore bodies could be cited near the Younger Greenstone-Older Greenstone, or lower contact."

This statement reveals that Dr. Stillwell has ignored the main points in our discussion of the relation of lodes and shears to major rock structures. Figures 10 and 11 clearly show that the productive lodes of the Eastern Lode System are clustered about the Australia East cross-fold. The vertical axial plane of the Australia East cross-fold would intersect the projected position of the overlying slate contact several thousand feet above the present surface. It is here and elswhere *vertically above* the productive lodes that we regard the slate contact as having possibly exerted its influence on ore deposition. It is certainly below here where the "numerous instances of high-grade ore bodies could be cited near the Younger Greenstone-Older Greenstone contact," and *not* at the south end where the slates outcrop.

At the surface the Australia East cross-fold is a mile away from the slate outcrops. And since the crenulated slate-Younger Greenstone contact pitches flatly south, the contact in depth lies farther and farther away from the Australia East cross-fold. It also lies farther and farther away from the southern limit of important ore bodies in either the Eastern or Western Lode Systems.

We regard the overlying slate contact as merely one of several structures that influenced ore deposition. Unless strong shears capable of supplying quantities of ore solutions to the contact existed in the underlying quartz dolerite, it is manifestly impossible for the contact to have localized large ore bodies. At the far south end where no such strong ore channels exist, the contact is nevertheless mineralized in the Imperial Mine. The ore solutions evidently made the best of a bad situation.

I wonder that the lack of important ore bodies at the far south end did not strike Dr. Stillwell as inconsistent with his own view that the ore solutions in large measure were discharged from the dikes on cooling (16, p. 69). There is no lack of dike tongues in this region.

Oroya Shoot.—Dr. Stillwell regards our statement that the Oroya Shoot is a " freak without parallel among ore bodies in the district both because of its unique geologic character and its remarkable continuity and richness " as an " exaggeration arising from over-emphasis of its structural features." Although he recognizes its unique structural features, and lists most of them, he apparently does not regard them as sufficient reason for the localization of the ore shoot. He believes rather that the controlling factor was a closely adjacent basic dike. His argument really rests on his theory that the lodes were formed from solutions emanating from the dikes. Spatially, the ore shoot is more closely identified with the pitching minor fold than with the dike. It is only where the ore-bearing fractures leave the fold in the Younger Greenstone-Older Greenstone contact and enter the body of the " calc schist " that the shoot dies. They leave the fold where it reverses its pitch temporarily on encountering the Australia East cross-fold. This reversal of pitch is clearly revealed by the drilling campaign recently completed by Lake View and Star in a search for the continuation of the ore shoot.

We contend that the shape and position of this ore shoot were *structurally controlled,* whatever the source of the ore solutions may have been. That it is unique structurally has not been gainsaid. As for its " remarkable continuity and richness," I quote Dr. Stillwell (16, p. 75), " The Oroya Shoot has been one of the most remarkable ore bodies ever known on account of its richness and length."

Ore Genesis.—As it stands, the last paragraph of Dr. Stillwell's discussion of the source of the ore solutions may puzzle some readers. Our theory and his, as he has defined them, contain no contradictions. It is necessary to go back to his earlier comments on the association of dike tongues and lodes, or better to page 69

of his Bulletin, in order to find out wherein we disagree. He concludes, "The nature of the relationship appears to be that of emanations and solutions partly intruded with the porphyry dikes and discharged on cooling and partly intruded as an aftermath following the course of the dykes and the fractures opened by their intrusion." He also on page 68 speaks of "discharged lode solutions . . . trapped within the dykes."

Dr. Stillwell, Dr. Miller, and I agree that there was an underlying batholith that ejected dikes and ore solutions. We disagree (*a*) in that he believes the lode fractures were caused to an important degree by the intrusion of dikes, whereas we consider that the shears occupied by the lodes were caused by rotational stress applied after solidification of the dikes; and (*b*) in that he regards a major portion of the lode material to have emanated from the dikes, whereas we believe that the ore solutions came from greater depths and were guided upward by post-dike shears.

It is manifestly impossible for these small dikes to have "trapped" enough ore solution or to have yielded enough ore solution as a result of differentiation in place to have produced the millions of tons of sulphides that were formed. In fact the total amount of lode material is probably greater than the total amount of dike material in the most productive portion of the field. Dr. Stillwell consequently must believe that the dikes served as conduits draining a larger reservoir of ore solution. Are the ore solutions visualized as bubbling up through the molten dikes and steaming off from them into the nearby shears until such a time as the dikes solidified? Since the ground-mass of the dikes is microcrystalline, the dikes must have solidified comparatively quickly. It is an interesting and necessary inference that ore deposits form in so short a space of time. Some such "bubbling process" as this probably does go on whereby ore solutions are funneled upward into cupolas below a solidifying magma crust to escape later when tapped by fractures penetrating the frozen crust. The evidence, however, strongly suggests to us that by the time the ore solutions were released, the dikes had solidified; and further, that during the later period of rotational

stress, dike contacts, like certain other structures, locally were places of comparatively easy relief. Some shears consequently formed at the dike contacts (though commonly the shears cut across them). We subscribe wholeheartedly to the generalization that there is a common association of porphyry dikes and ore deposits and that they are genetically related. We do, however, affirm that in Kalgoorlie there was a lag in time between dike intrusion and lode emplacement, and that the positions and shapes of Kalgoorlie ore bodies in a detailed sense are best explained by the structures we have indicated.

Composition of Older Greenstone.—Dr. Stillwell has correctly pointed out that the Older Greenstone lava flows are basalt. We erroneously dismissed them as " of intermediate composition."

J. K. GUSTAFSON.

BROKEN HILL, N. S. W.,
AUSTRALIA,
May 1, 1938.

REVIEWS

Geology and Ore Deposits of the Tombstone District, Arizona. By B. S. Butler, E. D. Wilson and C. A. Rasor.

The report on this old bonanza silver camp with its classic examples of saddle replacement deposits and veins is a welcome addition to the study of ore deposits. In its scope, the report covers a general geologic description of the rock formations, a detailed outline of the structure, and lastly, a careful and remarkably complete description of the ore occurrences, including the history and production record of the camp, a description of all the minerals of the camp and a final chapter devoted to conclusions as to future possibilities.

In the chapter on the general geology, the marked difference in physical characteristics between the competent thick-bedded Paleozoic beds and the incompetent relatively thin-bedded Cretaceous shales, limestones and quartzites is shown.

The following chapter on structure is the most interesting part of the report. The salient features are shown to be the Ajax Hill Horst to the south, in which Paleozoic sediments predominate, and the Tombstone Basin to the north of it in which Cretaceous sediments with dike intrusions of porphry crop out. The two are separated by a major fault known as the Prompter. The Tombstone Basin is bounded on the west by a strong reverse fault known as The Lucky Cuss. It is covered by recent valley fill on the east. West of The Lucky Cuss fault a large igneous mass crops known as the Schieffelin granodiorite which does not reach the boundaries of the basin. To the west of the Ajax Hill Horst occurs a second large igneous mass known as the Uncle Sam quartz latite porphyry. The horst-basin structure is shown to be caused by compressive stresses acting from the northeast to the southwest. The differences in results in the two areas are remarkable. In the Paleozoic beds cropping in the horst little or no folding occurs. The horst itself is cut up by faults into an irregular patch-work of fault blocks, in each of which the attitude of the beds is different. In the Cretaceous outcrops in the basin, on the other hand, the beds have been intricately folded. Close folds similar to salt dome structures are common. Another remarkable result of the compressive stresses in the basin is the development of low-

angle, reverse faults producing marked kaleidoscoping of certain limestone beds on the flanks of sharp anticlines and "rolls."

Developed in a late stage of the folding were, first, a northeasterly series of faults of minor throw, through which were intruded persistent narrow dikes of porphry. Five prominent dikes cut the area. Finally deep-seated fissures striking northeast which tended to swing into the previously developed dike fissures were developed. The major folding and later settling cracks and faults occurred in the northern part of the basin on the flanks of the synclinorium.

The chapter on ore deposits is remarkably complete considering the difficulties as the result of many caved and inaccessible workings. Some of the data was obtained from unpublished notes of F. L. Ransome and from information furnished by J. H. Macia, formerly mine superintendent of the old Tombstone Consolidated Company which operated in the early years of the century.

The structural details as related to ore occurrences are shown in great detail. Four general classes of ore bodies are shown to exist: Deposits associated with north-south (dike) fissures; deposits associated with faults; deposits associated with anticlines and "rolls"; and deposits associated with northeast fissures only. In all of them the ore occurs as replacements of various beds from the lower beds of the Paleozoic series to the upper sandstone and shale beds of the Cretaceous. The greater part of the production of the camp has, however, come from replacement deposits in the lower thin limestone and "novaculite" beds of the Cretaceous together with the contact of the Paleozoic Naco limestone and the Cretaceous basal quartzite.

In the deposits associated with north-south dike fissures, the chief deposit of this type being the Contention-Grand Central, the ore occurs as replacements of various beds from the upper Naco limestone of the Paleozoic to the middle of the Cretaceous. The thin basal limestone and "novaculite" beds of the Cretaceous series are especially favorable. Little replacement occurs in this type of ore bodies outside the fissure zone.

In the deposits associated with faults, most of which occur in the bounding fault zones of the Tombstone Basin, the Prompter and Lucky Cuss fault zones, the favorable horizons are, in general, the same as in the previously described type. Belonging to this type is the only deposit developed in the Ajax Hill Horst, the Emerald, in which the ore occurs in a northeast fissure where it cuts the Cambrian, quartzites and limestones of the Paleozoic series. Also belonging to this type is the State of Maine deposit in the Uncle Sam quartz latite porphyry. In this mine the ore occurs as replacements of both porphyry and included shale "horses" in a strong northeast fracture zone.

The principal and characteristic type of ore occurences is that associated with "rolls" and anticlines. In this class typified by the Toughnut, Silver Thread, West Side, Vizina and many others, the ore is shown to have been introduced along northeast fractures and to have replaced favorable beds both in the fractures and to considerable distances transversely along the flanks and crests of anticlines and "rolls." In general, the vertical horizon of replacement within the fractures is great, but bedded deposits transverse to the fractures are confined to certain favorable horizons chiefly at the Paleozoic-Cretaceous contact, and in the "novaculite" and limestone members at the base of the Cretaceous series. These features are shown well in the many detailed longitudinal sections along type fissures and "rolls."

General rules governing favorable conditions in the anticlines and "rolls" are shown to be: Deposits under impermeable shale caps; deposits in the more permeable and brecciated "novaculite"; deposits in more chemically permeable limestone beds (upper Naco limestone of the Paleozoic and "Blue" limestone of the Cretaceous); deposits associated with sharp bends varying in locality depending on the symmetry of the individual fold or "roll"; deposits along dike intersections with the "rolls"; deposits along the intersections of the "rolls" with the northeast ore channels. The deposits associated with northeast fissures alone, such as the Tombstone Extension, are closely allied to the third type, many of which, such as the West Side and Skip Fissure, contain both types of deposits.

The history of the camp is given from its discovery in 1877 to date, together with as complete as possible a summary of production. The grand total figure arrived at is $37,103,008.

A discussion of the distribution of minerals with the evidence of a crude zoning effect is given. In general a central high gold-fluorite-silica-molybdenum area occurs at the northeasterly end of the district surrounded by a zone in which silver predominates, surrounded finally to the south and southwest by a zone of manganese-silver-copper.

The last chapter concludes the report with a short discussion of the future possibilities. Many of the favorable structures in the various known "rolls" are shown to have been prospected in only a limited number of favorable horizons. The existence of ore below the water level is known, but the economic advisability of prospecting against the known heavy flow is left in abeyance.

The report was published by the Arizona Bureau of Mines under a cooperative agreement with the U. S. Geological Survey, which furnished the services of B. S. Butler and all available notes and maps of F. L. Ransome and others. The U. S. Geological Survey plans to issue a more

complete report on the district at some future date, in which, in addition to the surface geological map, a topographical map and a complete set of level maps will be added.

J. B. TENNEY.

TUCSON, ARIZONA,
July 6, 1937.

Die Lagerstätten der Nutzbaren Mineralien und Gesteine. Bd. III, Teil 2. Steinsalz and Kalisalz. By E. FULDA. Pp. 240; figs. 94. Ferdinand Enke Verlag, Stuttgart, 1938. Price 18.20 R. M.

This is a comprehensive discussion of sodium and potassium salt deposits. It includes accounts of the properties of the salt minerals, their origin, the geology and tectonics of their deposits and other matters of general interest relating to them. The greater portion of the volume, however, is devoted to the description of the deposits throughout the world. All that are known are listed, and most of them are described with sufficient fullness for the purposes of most readers. According to the author, many of them are described here for the first time in any general treatise. The rock salt deposits, salt wells and salt lakes of Russia and Siberia are treated by N. Polutoff.

The book is well illustrated and the text is well documented with many references.

W. S. BAYLEY.

Die Metallischen Rohstoffe. Heft 2. Molybdän, Monazit, Mesothorium. By PAUL KRUSCH. Pp. iv + 87; figs. 8. Ferd. Enke Verlag, Stuttgart, 1938. Price 6 Rm.

The second part of the treatise on metallic raw materials (see this journal, vol. 32, p. 1066) deals with molybdenum ores and monazite and discusses briefly mesothorium. As in the case of the earlier "heft" on vanadium, etc., there is nothing especially new in the treatment of molybdenum and monazite. The value of the publication lies in the fact that it furnishes an excellent summary of our knowledge of the character and use of the ores and their geographical distribution. The thoroughness with which the subject is covered may be indicated by the citation of 98 references to articles on molybdenite ores and 34 on those relating to monazite.

W. S. B.

Physiography of Eastern United States. By N. M. FENNEMAN. Pp. 714; figs. 197; pl. 7. McGraw Hill Book Co., New York, 1938. Price $6.50.

This is a companion volume to the *Physiography of the Western United States* that appeared in 1931, and the two together constitute a systematic

treatment of the country. The same procedure is followed, namely a detailed treatment of each physiographic province, such as the Piedmont, the Appalachian Plateau, or the New England Province. Thirteen such provinces are considered. The author has organized rather than assembled the vast amount of knowledge of these areas and in providing adequate physiographic descriptions of the country has elucidated the principles of geomorphology by the examples used.

The volume is comprehensive, carefully written, and well illustrated.

Regionale Geologie der Erde: Vol. I Die Alten Kerne; Part 5, Afrika. By E. HENNIG. (In German) Pp. 142; figs. 24. Akad. Verlagsgellschaft, Leipzig, 1938. Price 22 RM.

This is part of the new *Regional Geology of the Earth* that deals in detail with Africa. It treats of the important geologic events and results during each of the geologic periods in the different geographic sections of Africa. Numerous stratigraphic columns, maps, and sections illustrate the regional geology. It is detailed and complete. **Vol. II, Palaeozoische Tafeln und Gebirge, Part 2, Northwestern Europe, Caledonides.** By E. B. BAILEY and O. HOLTEDAHL. (In English.) Pp. 76; figs. 15; pl. 2. 1935. Price 14 RM. This part deals with the pre-Devonian, Devonian, and post-Devonian of Spitzbergen, Bear Id., Scandinavia, and British Isles. A large map depicts the Scandinavian Caledonian zone. Professor Bailey's intimate knowledge of this area assures completeness and authoritativeness. **Part 3, Mittel- und Westeuropa.** By HANS BECKER. (In German.) Pp. 99; figs. 31. 1938. Price 14 RM. This volume follows the same order as the others. The area is covered according to geologic units, each being treated chronologically.

These three new volumes constitute a welcome and useful addition to the Regional Geology of the Earth.

BOOKS RECEIVED.

J. D. BATEMAN.

Map of Bolivia. Designed and printed by JUSTUS PERTHES, Gotha, Germany. Scale, 1 : 1,000,000. Relief by contours of 100 and 500 m, also by colors. 4 sheets, size 58 × 76 in. Centro. de Propaganda y Defensa Nacional. 1938. For sale by International Map Co., 90 West St., New York. Price, $10. *A high quality, detailed topographic and cultural map, with marginal information.*

Geologic History of Magnolia State Park. W. C. MORSE. Pp. 19. Miss. Geol. Surv. Bull. 37, University, 1938. *Popular.*

Boletin de Geologia y Mineria. Vol. 1, Nos. 2–4. **First Venezuelan Geol. Congress, Caracas, Feb. 1937.** English ed. Pp. 309; maps. Min. de Fomento. Caracas, 1938. *Papers presented at Congress on Geology of Cordillera; Venezuelan Andes; Cretaceous beds of SW and N; Stratigraphy of Bolivar coastal, Mene Grande, Buchivacoa, Cumarebo, Maracaibo basin, Rio Querecual, Barinas, Punta Gavilan, Falcon; large mammals of Barquisimeto.*

Geology and Ground-water Resources of South-central Nebraska. AL. LUGN AND L. K. WENZEL. Pp. 242; pl. 16; figs. 21. U. S. Geol. Surv., W–S Paper 779. Washington, 1938.

Geology and Ore Deposits of Bayhorse Region, Custer Co., Idaho. C. P. Ross. Pp. 161; pl. 18; figs. 17. U. S. Geol. Surv. Bull. 877. Washington, 1938. *Stratigraphy, Cambrian to Quaternary; structure; gemorphology; lodes and mines of Pb, Ag, Cu, Zn, Au, Mo, Sb, As.*

Geophysical Abstracts 89, April–June, 1937. W. AYVAZOGLOU. Pp. 92. U. S. Geol. Surv. Bull. 895–B. Washington, 1938.

Geology and Mineral Deposits of the Snowmass Mountain Area, Gunnison Co., Colo. J. W. VANDERWILT. Pp. 184; pl. 24, figs. 23. U. S. Geol. Surv. Bull. 884. Washington, 1938. *Stratigraphy of pre-Cambrian to Tertiary and dike rocks, granite and granodiorite; contact-metamorphism; structure; glaciation; deposits of Ag, Pb, Cu, Zn in veins and replacements.*

Washability Characteristics of Illinois Coal Screenings. D. R. MITCHELL AND L. C. MCCABE. Pp. 84, figs. 14; tables 18. Urbana, 1938. Ill. Geol. Surv. Report of Investigations No. 48. Urbana, 1938.

Fluorspar Industry of U. S. with Special Reference to Illinois-Kentucky District. P. HATMAKER AND H. W. DAVIS. Pp. 128; figs. 14, tables 39. Ill. Geol. Surv. Bull. 59, Urbana, 1938. *Uses, statistics, districts, prospecting, mining, milling, markets, distribution.*

Variation in the Silica Content of the Water in Monterey Bay, Cal., During 1932, 1933 and 1934. AUSTIN PHELPS. Pp. 153–188. Trans. Amer. Philos. Soc. New Series, Vol. XXIX, Pt. 2, March, 1938. *Distribution of the silicate content of the water of Monterey Bay with reference to depth, season and temperature.*

Geological Map of Alberta. J. A. ALLAN. Scale 16 miles to 1 inch; 27 × 50 in.; colored. Geol. Surv., Edmonton, 1937. Price 75 cts.

West Half Opemisca Map-Area, Quebec (Preliminary). G. W. H. NORMAN. Pp. 15; geol. map. Can. Geol Sur. Pp. 38–11. Ottawa, 1938 (June). *General geology and gold-copper deposits.*

Limestones of Canada, Part IV, Ontario. M. F. GOUDGE. Pp. 362; pl. 46; figs. 10; maps, 2. Can. Bur. of Mines. No. 781. Ottawa, 1938. Price, 75 cts. *Part of a systematic survey; distribution, utilization, detailed properties, statistics.*

Ann. Report. Geological Survey, Uganda, for 1937. E. J. WAYLAND. Pp. 25; map. Entebbe, 1938. Price, 3 sh. *Account of year's operations.*

Cadillac Area, Quebec. H. C. GUNNING. Pp. 80; pl. 7; figs. 6; geol. maps, 2. Can. Geol. Sur. Mem. 206. Ottawa, 1937. Price, 25 cts. *Detailed geology of rich gold area, and of O'Brien, Thompson-Cadillac, Pandora and other gold mines; spectacular gold of O'Brien mine.*

Gold Deposits of Herb Lake Area, Manitoba. C. H. STOCKWELL. Pp. 46; figs. 6; geol. maps, 3. Can. Geol. Sur. Mem. 208. Ottawa 1937. *Geology of interesting pre-Cambrian area and included gold deposits.*

Report of Mines and Geology Branch for 1937. J. MCLEISH, Director. Pp. 38. Ottawa, 1938. *Operations of various departments for the year.*

Structural Materials of Tennessee Valley Authority Region. Pp. 25 (mimeograph); charts, 5. Div. of Geol. Bull. 6. Knoxville, 1937. *Structural materials, building and crushed stone; cement, lime and plaster industries.*

Geochemische Verteilungsgesetze der Elemente. IX. die mengenverhältnisse der elemente und der atom-arten. V. M. GOLDSCHMIDT. Pp. 148; figs. 6. Oslo, 1938. *Geochemistry of the elements and their amounts in nature; an outstanding contribution.*

Explanation of Degree Sheet 52, Dodona. By F. B. WADE AND F. OATES. Pp. 60; geol. map. Tanganyika Geol. Div. No. 17, Dar es Salaam, 1938. Price 3/–. *General geology; petrology of granite and gneissic igneous rocks; gold and non-metallics.*

Geology and Groundwater of the Valley of Gila River and San Simar Creek, Anyora. By M. W. KNECHTEL. Pp. 222; pl. 9; figs. 5. U. S. Geol. Surv. W. S. P. 796 F. 1938. Price 35 cts.

Geology and Fuel Resources of the Southern Part of the Oklahoma Oil Field. Part III, Quinton-Scipio district. By C. H. DAVE, H. E. ROTHROCK, J. S. WILLIAMS. Pp. 253; pl. 15; figs. 4. U. S. Geol. Surv. Bull. 874–C. 1938. Price 65 cts. *Detailed stratigraphy, paleontology, structure, of coal oil and gas fields.*

SOCIETY OF ECONOMIC GEOLOGISTS

The Society will hold a joint meeting with the Industrial Minerals Division of the A. I. M. E. in Knoxville, Tenn., Oct. 6 to 8. Headquarters at Hotel Farragut. Separate and joint sessions and excursions will be held. The tentative program follows:

TENTATIVE PROGRAM.

Thurs. Oct. 6: Joint Session, S. E. G. and A. I. M. E.

Chairmen, J. R. THOENEN AND D. H. MCLAUGHLIN.

10:00 A.M.	D. P. Hale, Jr.:	Recent improvements in mining and milling Cartersville Barite.
10:30	R. A. Laurence:	Barite deposits of Tennessee.
10:50	W. B. Jones:	The oolitic limestone deposits of Franklin Co., Ala.
11:10	T. L. Kesler:	The Ochre deposits of the Cartersville District, Ga.
11:40	N. C. Amick:	Tennessee slate.
12:00	N. A. Rose:	Rock asphalt deposits of Colbert Co., Ala.

P.M. Excursion to Electro-Technical Lab. U. S. Bur. Mines, at Norris, Tenn.—Chinaware operations.

Evening: Chairman, OLIVER BOLES.

8:00 P.M.	G. W. Bain:	Role of the geologist in the marble industry.
8:30	W. H. Runge:	Alabama marble.
9:00	G. M. Hall:	Pre-view of Friday's marble trip.

Friday, Oct. 7: Separate Meetings.

	S. E. G.	*A. I. M. E.*
	Chairmen:	
	CHARLES BEHRE, JR.	S. WALKER
9:00 A.M.	H. F. Kendall: Structural features of Ducktown ore bodies.	
9:30	C. S. Ross: Titanium deposits of the S. Appalachians.	E. R. Kendall: Methods used in prospecting for mineral aggregates.

9:55	L. W. Currier and J. Bridge: Appalachian zinc deposits.	W. E. Cate: Durability studies of aggregates.
10:20	F. L. Hess: Lithium pegmatites of the Carolinas.	F. Cadina: Production methods at Hiwassee dam aggregate plant.
10:40	Alice Allen and L. K. Sharpe: Mica pegmatites of N. Carolina.	Paul Wier: Use of bleaching clays in water purification.
11:00	C. S. Blair: Coals of the southern Appalachian fields.	

Joint Session: Chairmen, G. R. MANSFIELD, AND WM. D. JOHNSTON, JR.

11:30	B. C. Moneymaker and P. P. Fox: Use of large diameter core drill in geological explorations.
12:00	B. C. Moneymaker: Building stones of North Carolina.

P.M. Excursion: Grand Knox Marble Co. Quarry, Asbury, Tenn. and adjacent Lime Plant

Evening: Joint Session

7–8:30 P.M.	Joint Dinner, S. E. G. and A. I. M. E. Prof. N. C. Daugherty, Dept. of Civil Engineering, Univ. of Tennessee, Toastmaster.
8:30	C. S. Maurice: Comparison of feldspar deposits of Spruce Pine with those of Europe.
9:30	H. O. DeBeck: Feldspar mining in North Carolina.
9:30	Chas. Oder: The Mascot mine (preview of Saturday's inspection trip).
9:45	B. C. Burgess: The Spruce Pine mineral deposits (preview of Saturday's inspection trip).

Saturday	A.M.	Excursion: Mascot zinc mines.
	P.M.	Football game: Univ. of Tenn. vs. Alabama Poly. Inst.
or:		All day joint excursion (tentative) to Spruce Pine District, N. Carolina.

SCIENTIFIC NOTES AND NEWS

R. M. DICKEY has been promoted to full professorship and head of the Geology Department of Michigan College of Mining and Technology and KIRIL SPIROFF has been made curator of the A. E. Seamen Mineralogical Museum.

J. A. DUNN of India is visiting in Australia.

D. H. MCLAUGHLIN of Harvard is in Mexico on professional business.

JAMES GILLULY has left the U. S. Geological Survey to become head of the Department of Geology at the University of California in Los Angeles.

H. H. READ, Herdman professor of Geology, Univ. of Liverpool, succeeds Prof. C. H. Boswell as professor of Geology in the Imperial College.

W. T. THORN, JR. of Princeton has taken a group of geology students to the Big Horn Basin, Yellowstone Park, and to study the natural resources of the Gulf Coast region.

W. B. HEROY of New York has been appointed Vice-President and chief geologist of the Pilgrim Exploration Co. with headquarters in Houston where his entire time will be devoted to the company's interests in Louisiana, Texas, and Arkansas which are jointly held with Folis Oil Co.

A. A. MACKAY of Alderson and MacKay has returned to Montreal from a trip to England.

R. S. MOEHLMAN of the Anaconda geological department has been transferred from Butte to Inspiration, Ariz.

PHILIP KREIGER of Columbia Univ. has been in Mexico for the summer.

IRA B. JORALEMON is on an extensive tour of Europe with his family.

P. H. PRICE has been appointed head of the department of geology at West Virginia University, Morgantown.

FRANK AYER has returned to Roan Antelope after a visit to the United States.

W. R. APPLEBY has retired as Dean of the Mining School, Univ. of Minnesota.

F. G. FORMAN, government Geologist of W. Australia will study at Harvard under a Commonwealth Fellowship.

R. M. HERNON has been appointed assistant professor of Geology at the Univ. of Arizona.

A. P. BEAVAN, formerly of Princeton, is geologist for O'Brien Gold Mines, Kewagamo, Ont.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS will hold their mid-year meeting at El Paso, Texas, Sept. 27–Oct. 2. Three post-meeting excursions will be held; 1, to Chihuahua City, Mex.; 2, Carlsbad; 3, Malone, Quitman and Davis Mountains.

ADVERTISEMENTS

Patrons of this journal are requested to refer to ECONOMIC GEOLOGY when consulting advertisers.

A Complete Plant Under One Roof

PRINTING ~ BINDING ~ ELECTROTYPING

Printers of
Scientific and Technical Journals and Books
Theses and Dissertations
Works in Foreign Languages

Your Book, Journal or Thesis placed with us insures that the composition, proof-reading, electrotyping, presswork and binding, follow through in consecutive order in one plant—established sixty-one years ago—and under the supervision of one management. : : :

LANCASTER PRESS, Inc.

Established 1877 **LANCASTER, PA.**

[*Printers of Economic Geology*]

Minerals and Rock Specimens

Large variety of MINERALS by weight for class work and for laboratory purposes. Freight paid on all shipments valued at $25 and over.

R. M. WILKE, Box 312 **PALO ALTO, CALIF.**

·PHOTO-ENGRAVINGS OF SUPERIOR QUALITY·

the Stoddard · Engraving · Company ·

INCORPORATED

87 ORANGE STREET

New Haven · Connecticut

THIN - SECTIONS
AND
POLISHED SECTIONS

Prices reasonable

RUDOLPH VON HUENE
822 DOS ROBLES PLACE
ALHAMBRA, CALIF.

FOR SALE

SET OF THE TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. 74 VOLS.

ALL IN STANDARD BINDING AND GOOD CONDITION

Vols. 1 to 66 & 68 to 75; index vols. 1–10; 1–15; 1–25; 26–30, together with 7 vols. American Society of Mechanical Engineers, vols. 41–47, two unbound.
Price f.o.b. destination - - - $175

Address: P. T. BISSELL, 629 S. Main St., Geneva, N. Y.

VOL. X, NO. 2

of the

ANNOTATED BIBLIOGRAPHY OF ECONOMIC GEOLOGY

is now ready for mailing.

Order from

ECONOMIC GEOLOGY PUBLISHING CO.
URBANA, ILL.

GEOLOGISCHES ZENTRALBLATT

ABTEILUNG A: GEOLOGY

GEOLOGISCHES ZENTRALBLATT appears on the first and fifteenth of each month in parts containing 4–5 signatures. Nine parts constitute a volume. Fifty-six volumes (1901–1936) have been published.

ABTEILUNG B: PALEONTOLOGY

PALAEONTOLOGISCHES ZENTRALBLATT appears in a single part of 4–5 signatures each month. Eight parts constitute a volume.

The price per volume of the Geologischen Zentralblatt (Abt. A) is 48 Rm.

The price per volume of the Palaeontologisches Zentralblatt (Abt. B) is 48 Rm.; seven volumes have appeared.

Address: *Gebruder Borntraeger*, Berlin, W. 35., Germany

SOCIETY OF EXPLORATION GEOPHYSICISTS

(Formerly Society of *Petroleum* Geophysicists)

The change in name was made to indicate more clearly the close identification of the Society's aims and objects with the recent recognition that exploration is inherently a primary division of the petroleum industry.

The Society's publication "Geophysics" will remain as the medium for public presentation of papers dealing with the more important phases of exploration for natural resources, which meet the scientific standards established in the past by the Society, and maintained continuously by the Editor, Dr. M. M. Slotnick, and the past Editor, Dr. F. M. Kannenstine.

Application for membership in the Society and subscriptions to "Geophysics" should be made through

M. E. STILES, *Secretary-Treasurer*,
2011 Esperson Bldg., Houston, Texas.

Subscription Rates (Non-members):	U. S. A.	Foreign
Yearly	$6.00	$6.50
Single copies	$3.00	$3.50

KEEP UP WITH PROGRESS

Take Photomicrographs in NATURAL COLORS

Micro Ibso Attachment with Leica, Microscope and Light Source

THE outstanding effects produced by minerals when observed in polarized light are their interference colors. Only with a film which reproduces these colors faithfully is it possible for the mineralogist to derive full benefit from photomicrographs taken in polarized light. The Leica camera accommodates Kodachrome film and, with the Micro Ibso Attachment, can be adapted to any polarizing microscope. This equipment makes photomicrography in colors a simple routine procedure. The pictures can be projected or reproduced as color halftones in publications.

Ask for reprint of "Identification of Sulphide Minerals by Selective Iridescent Filming" by A. M. Gaudin (Techn. Publ. No. 912, Am. Inst. of Min. & Met. Engrs.) with twelve reproductions of photomicrographs in color, as well as literature about the equipment.

E. LEITZ, INC. 730 FIFTH AVENUE, NEW YORK, N. Y.
WASHINGTON · CHICAGO · DETROIT
(Makers of the famous LEICA Cameras) Western Agents: Spindler and Sauppe, Inc., Los Angeles · San Francisco

AN INDEX

of the first ten volumes

of the

ANNOTATED BIBLIOGRAPHY OF ECONOMIC GEOLOGY

will be published in the Fall

Price $5.00

Order from

ECONOMIC GEOLOGY PUBLISHING CO.

URBANA, ILL.

MAAS Determines Direction and Dip of Drill Holes

Drill Hole Compass

E. L. DERBY, Jr., Agent, Ishpeming, Michigan

14-7 CODE: McNeill's, 1908

LABORATORY FOR ROCK ANALYSES

Chemical analyses of rocks and rock minerals made with the accuracy required for research work in petrography: for students, geologists, and surveys. Moderate prices.

FRANK F. GROUT, in charge

GEOLOGY DEPARTMENT, UNIVERSITY OF MINNESOTA

MINNEAPOLIS, MINNESOTA

A New A. A. P. G. Book

GULF COAST OIL FIELDS

A Symposium by Fifty-Two Authors

Forty-four papers reprinted from the Bulletin of The American Association of Petroleum Geologists, with a Foreword and an explanation for reading an aerial photo-mosaic by Donald C. Barton.

Edited by

DONALD C. BARTON, Humble Oil and Refining Company

GEORGE SAWTELLE, Kirby Petroleum Company

I. General and Theoretical—14 papers

II. Stratigraphy—10 papers

III. Oil Fields and Salt Domes—24 papers

This book supplements *Geology of Salt Dome Oil Fields* (1926; edition sold out). This new book is the response to a large demand. *Order your copy now. Notice the low price.*

* 1,084 pages; 292 figures; 19 halftone plates.
* Blue cloth; gold stamped; paper jacket; 6 x 9 inches.
* Price: $4.00, delivered. $3.00 to A. A. P. G. members and associates.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Box 979, Tulsa, Oklahoma

NEW BOOK LIST

The books in the following list are all recent publications. Copies will be sent to any address in the United States, Canada or Mexico on receipt of the prices opposite the titles. Address ECONOMIC GEOLOGY, Urbana, Ill. Books not in this list will be furnished at Publishers' prices. THE PRICES OF ENGLISH BOOKS ARE QUOTED WITHOUT DUTY. THE PRICES OF ALL FOREIGN BOOKS VARY WITH THE EXCHANGE.

The Geology of Venezuela and Trinidad. By R. A. LIDDLE. Pp. xlii + 546. Illus. 169, Sections, etc., 24. Cloth, 6 x 9 ..... 7.50

Ore Deposits of Magmatic Origin. By P. NIGGLI. Trans. by H. C. BOYDELL 2.70

Guide to the Study of Non-Metallic Mineral Products. By W. S. BAYLEY. Pp. 530. Illus. 127. Maps. Cloth, 6 x 9 ..... 4.00

Field Geology. 3d Ed. By F. H. LAHEE 5.00

German-English Geological Terminology. By W. R. JONES and A. CISSARZ. Pp. xv + 250. Cloth. 3.25

A Descriptive Petrography of the Igneous Rocks. Vol. I. By A. JOHANNSEN. Pp. xii + 268. Figs. 145. Cloth, 6¼ x 9¼ 4.50

Vol. II. The Quartz-bearing Rocks. Pp. xxix + 429. Illus. 119. Cloth 5.50

A French-English Vocabulary in Geology and Physical Geography. By G. M. DAVIES. Pp. ix + 140. Cloth, 8vo 1.75

Treatise on Sedimentation. 2d Ed. Rewritten. By W. H. TWENHOFEL. Pp. xxvi + 914. Figs. 121. Cloth, 6 x 9 ..... 8.00

Igneous Rocks and the Depths of the Earth. By R. A. DALY. Pp. 598. Illus. Cloth, 6 x 9 ..... 5.00

Metamorphism. By A. HARKER. Pp. ix + 260. Figs. 185. Cloth, 6 x 9 ..... 5.00

Thin Section Mineralogy. By A. F. ROGERS and P. F. KERR. Pp. xii + 311. Figs. 261. Cloth 3.00

Mineral Deposits. 4th revised Ed. By W. LINDGREN 6.50

The Determination of the Feldspars in Thin Section. By K. CHUDOBA. Trans. by W. R. KENNEDY. Pp. 75. Figs. 50. Cloth, 8vo 1.75

Die Bodenschätze des Staates Minas Geraes, Brasilien. By B. v. FREYBERG. Pp. xvi + 453. Figs. 73. Pl. 12. Paper 20.50

Grundzüge der Geologie und Lagerstättenkunde Chiles. By J. BRUGGEN. Pp. viii + 362. Figs. 69. Pl. 4. Paper 13.25

The Strategy of Raw Materials. By B. EMENY. Pp. 202. Maps, etc., 29 ..... 3.00

The Examination of Fragmental Rocks. By F. G. TICKELL. Pp. 127. Figs. 51. 6¾ x 10 ..... 5.00

Handbook for Prospectors. 3d Ed. By M. W. VON BERNEWITZ. Pp. 372. Illus. 105. Cloth, 5 x 7¼ 3.00

Sahara, The Great Desert. By E. F. GAUTIER. Trans. by D. F. MAYHEW 3.75

Einführung in die Geologie. By HANS CLOOS. Pp. xii + 503. Figs. 356. Pls. 3. Cloth, 10 x 7 ..... 9.65

Section de Géologie Appliquée. Vols. I and II Congrès Intern. des Mines, etc. Seventh Session Pp. 1100. Paper, 23 x 28.5 cm 8.75

Interpretative Petrology of the Igneous Rocks. By H. L. ALLING. Pp. 350 +. Illus. Cloth, 6 x 9. 4.00

Economic Geology of Mineral Deposits. By E. R. LILLEY. Pp. x + 811. Figs. 300. Cloth 5.10

Prospecting and Operating Small Gold Placers. 2nd Ed. By W. F. BOERICKE. Pp. 144. Illus. 30. Cloth, 5 x 7½ 1.50

Mineral Industry. Vol. 45, 1936. By G. A. ROUSCH. Pp. 800. Cloth, 6 x 9 ..... 12.00

The Geology of Southwestern Ecuador. By G. SHEPPARD. Pp. xi + 275. Illus. 195. Cloth 6.25

Coal, its Constitution and Uses. By W. A. BONE and G. W. HIMUS. Pp. xvi + 631. Figs. 134. Pl. 29. Cloth 7.50

Geologie von Asien. Vol. I. Th. 2. By K. LEUCHS. Pp. viii + 317. Figs. 144. Paper, 10⅝ x 7 ..... 8.00

Gold Deposits of the World. By W. H. EMMONS. Pp. 552. Illus. Cloth, 6 x 9 ..... 6.00

Elements of Optical Mineralogy. Pt. I. **Principles and Methods.** 5th Ed. By A. N. WINCHELL. Pp. 263. Illus. 305. Cloth, 6 x 9 ..... 3.50

Die Metallischen Rohstoffe. By P. Krush. Heft I. Vanadium, Uran, Radium. Pp. 156. Figs. 17. Paper 3.75

Das Magma und seine Produkte. By P. Niggli. Th. I. Physikalisch-chemische Grundlagen. Pp. xi + 370. Figs. 275. Paper 11.00

Petroleum Technology, 1936. By Inst. Petrol. Geol. Pp. viii + 326. Illus. 8. Cloth 2.00

Geologisches Wörterbuch. By C. C. BERINGER. Pp. vii + 126. Illus. 51 ..... 2.75

Engineering Geology. 5th Ed. By RIES & WATSON. Pp. 750. Illus. 407. Cloth, 6x9 ..... 5.00

Ground Water. By C. F. TOLMAN. Pp. 576. Illus. Cloth, 6 x 9 ..... 6.00

Mineral Raw Materials. By MEMBERS U. S. BUREAU OF MINES. Pp. 342. Charts 65. Cloth, 6 x 9 5.00

Geological Nomenclature. Edited by L. RUTTEN Pp. viii + 339 Illus. 58. Cloth, 8 x 11 ..... 6.75

Professor David. By M. E. DAVID. Pp. 320. Pl. 8. Map. Cloth 5.00

The Cycle of Weathering. By B. B. POLYNOV. Trans. by A. MUIR. Pp. xii + 220. Cloth, 5½ x 8½ 2.75

Our Wandering Continents. By A. L. DU TOIT. Pp. 364. Illus. 48. Cloth, 8vo 4.75

The Geology and Biology of the San Carlos Mountains, Tamaulipas, Mex. By L. B. KELLUM and others. Pp. xi + 341. Pl. 30. Figs. 18. Maps 13. Cloth, 8x11¼ 5.00

Outlines of Historical Geology. 3rd Ed. By C. SCHUCHERT and C. O. DUNBAR. Pp. 241. Illus. 151. Cloth, 6 x 9 ..... 2.50

Principles of Structural Geology. 2d Ed. By C. M. NEVIN. Pp. 348. Figs. 163. Cloth, 6 x 9 ... 3.50

Economic Geology. 7th Ed. By H. RIES. Pp. 720. Figs. 378. Cloth, 6 x 9 ..... 5.00

Edward Wilson of the Antarctic. By GEO. SEAVER. Pp. xxxiv + 301. Pl. 17. Maps 2. Cloth, 6 x 9 ..... 3.00

Earth Lore. By S. J. SHAND. Pp. viii + 144. Figs. 33. Cloth, 5¼ x 7½ 1.75

Landslides and Related Phenomena. By C. F. S. SHARPE. Pp. xvi + 137. Illus. Cloth 3.00

The Science of Petroleum. By 300 authorities. 4 Vols. 85.00

Scientific Illustration. By J. L. RIDGWAY. Pp. 210. Illus. Cloth, 7 x 10 ..... 4.00

Methods in Paleontology. By C. L. CAMP AND G. D. HANNA. Pp. 153. Illus. Cloth 2.50

Ueber die Bildung und den chemischen Bau der Kohle. By P. ERASMUS. Pp. viii + 121. Paper, 8vo 4.00

Die Metallischen Rohstoffe. Heft. 2. By P. KRUSH. Molybdan, Monazite, Mesothorium, Pp. iv + 87. Figs. 8 ..... 2.40

Die Wichtigsten Lagerstätten der "Nicht-Erze." Bd. III. Teil 1. Steinsalz und Kalisalze, Geologie. By F. LOTZE. Pp. xxvii + 936. Figs. 353 ..... 32.00

Die Lagerstätten der Nutzbaren Mineralien und Gesteine. Bd. III. Teil 2. Steinsalz und Kalisalz. By E. FULDA. Pp. 240. Figs. 94. Paper 7.00

Dynamik der deutschen Acker- und Waldböden. By W. LAATSCH. Pp. xi + 270. 4 Pl. 56 Figs. Paper, 8vo 8.25

Introductory Economic Geology. 2d Ed. By W. A. TARR. Pp. 631. Illus. Cloth, 6 x 9 ..... 5.00

The Origin of Life. By A. I. OPARIN. Trans. by S. MORGULIS. Pp. 270. Cloth 2.75

Studies on the Periodicity of Earthquakes. By CHAS. DAVISON. Pp. ix + 108. Figs. 14. Cloth, 8½ x 5½ 3.50

Minéralogie von Bolivien. By F. AHLFELD and J. M. REYES. Pp. viii + 89. Figs. 30. Paper, 10 x 6½ 4.25

Outlines of Geomorphology. By S. W. WOODRIDGE and R. S. MORGAN. Pp. xxi + 445. Figs. 272. Cloth, 6 x 9 ..... 4.50

Annual Reviews of Petroleum Technology. Vol. 3. Pp. viii + 490. Illus. 9. Cloth 3.00

Practical Oil Geology. 5th Ed. By D. HAGER. Pp. 455. Illus. Cloth, 6 x 9 ..... 4.00

The Principles of Soil Science. By A. A. J. DE SIGMUND. Trans. by A. B. YOLLAND. Pp. xiv + 362. Figs. 34. Pl. 4. Cloth, 6 x 9 ..... 5.70